GLIDING AN AIRBUS A320

Simplicity-Complexity Trade-Off

Cristian Mandu | LUND UNIVERSITY

Gliding an Airbus A320

Simplicity-Complexity Trade-Off

Cristian Mandu

Under the supervision of Anthony Smoker, PhD.

Lund 2021

Gliding an Airbus A320; Simplicity-Complexity Trade-Off

Cristian Mandu, under supervision of Anthony Smoker, PhD.

Number of pages: 138
Illustrations: 81

Keywords
Aviation, Crew Resource Management, Workload, Situational Awareness, Decision Making, QRH procedure, Judgment Heuristics, Joint Cognitive Systems.

Abstract

In the unlikely critical event of an Airbus A320 aeroplane suffering an all engines failure at cruising altitude, would the pilots be able to follow procedures and land safely on a reachable runway? Nine out of twelve simulations done during this research resulted in a crash when the pilots used only the Airbus procedures. Can the pilots make a safe landing on a runway after being taught and having practised judgment heuristics in addition to the manufacturer procedures? According to the sampled results in this research, they can. All of them.

This research proposes an experimental comparative simulation design, drawing upon the Cognitive Systems Engineering approach, exploring the contribution of judgment heuristics – as a feedforward artefact addition to the manufacturer procedure – to manage the situation. The results point to a significant benefit of adding judgment heuristics to the pilots' 'toolbox'. The conclusion proposes further research to explore the potential benefits of training pilots the use of judgment heuristics for other critical situations as part of the airline pilot training syllabus. It also suggests a re-design of the Airbus A320 ALL ENGINES FAIL procedure.

Riskhantering och samhällssäkerhet
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

http://www.risk.lth.se

Telefon: 046 - 222 73 60

Division of Risk Management and Societal Safety
Faculty of Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

http://www.risk.lth.se

Telephone: +46 46 222 73 60

Preface

This research proposes a comparative experimental simulation of an ALL ENGINES FAIL emergency on board an Airbus A320, aiming to see how judgment heuristics contribute to the pilots' management of the glide.

When dealing with an ALL ENGINES FAIL situation, if the engines cannot be restarted, the airline pilots suddenly become glider pilots, and they have to choose between making a forced landing or ditching. A forced landing can be on a runway or anywhere else, e.g., an open field or a highway. Ideally, the pilots will manage to land on a runway. This situation presents two significant challenges: calculating if a runway can be reached and monitoring the calculated profile throughout the descent, correcting eventual deviations. Simultaneously, the pilots will try to relight the engines and follow the procedure as thoroughly as possible. The workload and cognitive task load increase significantly and suddenly.

This research observes and compares how airline crews manage this failure using only the manufacturer procedure and how they manage the same situation after being briefed and trained on the use of simplified 'rules-of-thumb' type of heuristics in addition to the manufacturer procedure. After each simulation, the crews were required to complete a rating scales based instrument that measured their perception of situational awareness, workload and decision making. The comparative results are analysed, drawing upon a Cognitive System Engineering approach (Hollnagel & Woods, 2005).

The results indicate a significant benefit in training the pilots in the use of judgment heuristics as an addition to the ALL ENG FAIL manufacturer procedure. The conclusion proposes further research on the potential benefits of training judgment heuristics on other emergencies as part of a pilot training syllabus.

Acknowledgements

To reach this point in the Lund program has been an extraordinary journey. At the start of it, I was self-confident that I will demonstrate what I thought I knew. At the end of the journey, I embrace the humbleness of having an endless number of questions. This journey was also accompanied by many changes in my private and professional life. This research was conducted in the context of the COVID-19 pandemic restrictions. I could not have done it alone. I am grateful for the support I have received from my family, friends, and fellow student colleagues.

I'd like to thank Dr Anthony Smoker for encouraging me to join Lund University and for mentoring me throughout the program. Special thanks also go to Tudor Adrian Gînga, Teodora Iulia Grama, Arina Cocoru, Radu Poenaru, Michael Watt, Anca Dumitru, Zsuzsa Marton, and Nibedita Rath for their invaluable support, encouragement, and involvement with various tasks required to complete this research.

Finally, I'd like to thank all the volunteer pilots who took part in the simulations, the Wizz Air Pilot Academy, for granting me access to their simulator in Budapest, and my team colleagues at FlightX for granting me the simulator in Cluj-Napoca.

What an extraordinary journey in the middle of a pandemic!

Abstract

In the unlikely critical event of an Airbus A320 aeroplane suffering an all engines failure at cruising altitude, would the pilots be able to follow procedures and land safely on a reachable runway? Nine out of twelve simulations done during this research resulted in a crash when the pilots used only the Airbus procedures. Can the pilots make a safe landing on a runway after being taught and having practised judgment heuristics in addition to the manufacturer procedures? According to the sampled results in this research, they can. All of them.

This research proposes an experimental comparative simulation design, drawing upon the Cognitive Systems Engineering approach, exploring the contribution of judgment heuristics – as a feedforward artefact addition to the manufacturer procedure – to manage the situation. The results point to a significant benefit of adding judgment heuristics to the pilots' 'toolbox'. The conclusion proposes further research to explore the potential benefits of training pilots the use of judgment heuristics for other critical situations as part of the airline pilot training syllabus. It also suggests a re-design of the Airbus A320 ALL ENGINES FAIL procedure.

List of tables

List of figures

Glossary

ATC: Air Traffic Control, usually represented by the route, approach, or tower controllers.

CRM: Crew Resource Management (CRM) is mandatory training for airline crews. It promotes the use of all available resources to achieve a safe, effective, and efficient flight. The training theoretically covers startle effect, stress & workload management, situational awareness, decision making, leadership and teamwork, and resilience development (EASA, 2016; European Union, 2011).

Ditching: Making a forced landing on water (sea, river, or lake).

ECAM: Electronic Centralised Monitoring system. An electronic system that identifies the failure and presents the step-by-step guidance that pilots must follow.

FCTM: The Flight Crew Techniques Manual (FCTM) provides complementary information to the Flight Crew Operating Manual (FCOM): the general Airbus operational philosophy (e.g., design and utilisation principles, Golden Rules for pilots), additional information to the FCOM procedures (the “why" to do and the “how" to do), best practices, operating techniques on manoeuvres, and handling - Information on situation awareness. (Airbus, 2019b, GI P 1/22)

FL: Flight Level. The altitude at which an aeroplane flies, based on a standard altimeter setting. In this way, all flying aircraft use the same altimeter data to ensure vertical separation between them.

IAS: Indicated Air Speed. The air speed indicated on the main speed tape in the A320 cockpit.

ILS: Instrument Landing System. A ground-based guidance system that allows the aeroplanes to follow a precise lateral and vertical final approach profile to reach the runway touch down zone.

PF: Pilot Flying – the pilot that controls the aeroplane.

PM: Pilot Monitoring – the pilot that monitors and assists the pilot flying to control the aeroplane.

QRH: The Quick Reference Handbook is a printed or electronic document that is quickly available to the pilots on the flight deck. It includes a chapter on abnormal procedures.

SOP: Standard Operating Procedures. According to their role, procedures are learned and applied by all the crew members of an airline.

Type-rating: Training course for pilots. During type-rating, the pilots learn how to fly a specific type of aeroplane. E.g., Boeing 737, Airbus A320.

Contents

1 Gliding an Airbus A320; Simplicity-Complexity Trade-Off

My Interest in this research topic originates from my professional experience. I am an Airbus A320 training captain and a Crew Resource Management (CRM)[1] instructor working for an airline in Europe and the Middle East. Pilots learn and follow numerous procedures for both normal and abnormal situations. In abnormal and emergency situations, pilots may be affected by a sudden increase in cognitive workload or by the effects of startle and surprise, which can impact their cognitive capacity (Jarvis et al., 2014, Amalberti, 2001; DeLisi, 2018; EASA, 2018; FAA, 1996; Grant & Booth, 2009; Landman et al., 2017a; Landman, Groen, van Paassen, Bronkhorst, & Mulder, 2017b; Leach, 2004; Moriarty, 2015; Rankin et al., 2013, 2015; Talone & Jentsch, 2015).

On many occasions, trainers and more experienced pilots taught me alternative simplified ways to manage complex situations in a mentally economical way. This simplified verbal knowledge – "easily applied procedures for approximately calculating some value." ("Rules of Thumb," n.d.) – is not present in any Airbus or training documentation.

I chose to research how such verbal knowledge contributes to the management of an ALL ENGINES FAIL at cruising altitudes situation in an Airbus A320, which I believe is an excellent example of a complex and time-pressured situation that may expose the crew to the effects of a sudden increase in cognitive workload.

In the past, the most common cause of all engines failure was fuel starvation, but there have been other cases due to bird strikes, various forms of water ingestion such as hail, ice, heavy rain, flying through volcanic ash, or debris ingestion. Despite their low frequency, such failures have a high impact on the outcome. The aviation-safety.net database lists 280 cases of all engine power losses from 1941 to 2020, out of which 189 cases performed a forced landing outside the airport and 30 cases ditched ("All Engine Powerloss," n.d.).

From a pilot's perspective, an aeroplane whose engines have all failed suddenly becomes a heavy glider. Unless at least one engine can be restarted, deciding on a landing spot – ideally a runway – becomes the critical area of concern. The crew is faced with a set of challenges in calculating and controlling the glide path. An A320 crew may be startled and surprised following the sudden change from normal work to a critical situation with an increased workload, and the pilots may not be able to use the navigational guidance available in the Airbus Quick Reference Handbook (QRH)[2] due to lack of training.

[1] Crew Resource Management (CRM) is a mandatory training for airline crews. It promotes the use of all available resources in order achieve a safe, effective, and efficient flight. The training theoretically covers topics such as startle effect, stress & workload management, situational awareness, decision making, leadership and teamwork, and resilience development (EASA, 2016; European Union, 2011).

[2] The Quick Reference Handbook (QRH) is a printed or electronic document that is quickly available to the pilots on the flight deck. It includes a chapter of abnormal procedures.

The regulatory document for training Airbus A320 pilots is the *Airbus A320 Flight Crew Training Standards* (Airbus, 2019e). The ALL ENG FAIL procedure is defined as a Training Level E item:

> Training level E applies to items related to the knowledge, skill and attitude of a system operation or a procedure/technique that need to be trained as a flight crew:
>
> - In a full task training device with "psychological" capability that has:
>   - Maneuver capability in real time
>   - Full flight environment simulation capability.
> - With instructor guidance.
>
> The term "psychological" refers to the capability of the full task training device in which the tasks performed by the flight crew have a similar physical and emotional impact as they would have when the flight crew operates the real aircraft.
>
> Examples of training media level E: Full Flight Simulator (FFS). (Airbus, 2019e, p.74)

The document lists the ALL ENGINES FAIL situation as a mandatory item during type-rating but does not specify that the simulation must continue with the failed engines all the way to landing.

In May 2010, when I did my A320 type-rating at the Airbus Training Centre in Toulouse, I practised the ALL ENG FAIL procedure, but the exercise focused on restarting the engines. I was not trained on how to interpret and apply the navigational guidance presented in the QRH. I argue that the ALL ENG FAIL procedure is very complex and requires not only a sound prior structural understanding but also a lot of cognitive capacity to manage in accordance with the manufacturer guidance:

The Airbus Flight Crew Techniques Manual (FCTM) instructs the pilots first to follow the Airbus golden rule #1: "*fly, navigate, communicate: in this order and with the appropriate task sharing"* (Airbus, 2019a, PR-AEP-ENG P 5/24).

Figure 1. Airbus Golden Rules (Airbus, 2019a)

The Airbus "Golden Rules for Pilots" are a form of high-level operational guidelines that consider the "adaptation of basic flying principles to modern-technology", provide "information about the required crew coordination" while also taking into account CRM principles, aiming to ultimately "help prevent the causes of many accidents or incidents and to ensure flight efficiency." (Airbus, 2019a, AOP-40 P 1/4) As high level operational guiding principles, I argue they remain highly underspecified.

After complying with golden rule #1, the pilots must turn to the situation-specific checklists and procedures. Following all engine failure, there are significant changes in the electrical and hydraulic systems (Airbus, 2019a, PR-AEP-ENG P 2/24) which suddenly trigger a separate task-sharing situation on the flight deck.

Pilot Flying (PF), in this case, the pilot occupying the left seat, deals with coordinating and controlling the aeroplane trajectory (*fly*, *navigate, communicate*) and, provided fuel is still available, maintaining sufficient airspeed that would eventually allow the windmilling engines to relight. The Pilot Monitoring (PM), occupying the right seat, attempts to relight the engines by following the Electronic Centralised Monitoring system (ECAM)[3] and running through the QRH procedure (Airbus, 2019b, PR-AEP-ENG P 5/24). The ECAM and the QRH offer rough gliding range information in no wind conditions, based on performance envelope (factory) data.

> As a result, depending on actual parameters, the actual gliding distance may differ. After their range assessment, the PF should then initiate the diversion to an accessible runway, or determine the most appropriate area for a forced landing or ditching. (Airbus, 2019b, PR-AEP-ENG P 5/24)

If a runway is accessible and within the gliding range envelope, is it possible to effectively *fly* and *navigate* an Airbus A320 with failed engines from cruising altitudes to reaching a desirable outcome (safely landing and stopping on the runway), using only the guidance offered by the manufacturer procedure? I doubt it. I believe there is a gap in the procedure design and training standards:

Firstly, I argue that considering the potential effects on pilots' cognitive capacity following surprise and the sudden increase in workload in the cockpit, the Airbus A320 ALL ENG FAIL QRH

[3] Electronic Centralised Monitoring system (ECAM). An electronic system that identifies the failure and presents the step-by-step items that pilots must follow.

procedure offers flight crew anything but navigational *sensemaking* guidance (Rankin, Woltjer, & Field, 2016). Secondly, the Airbus Training Standards regulatory document does not require training pilots this level E procedure/technique to a sufficient level of knowledge and skill (Airbus, 2019e, p.74) that would enable them to demonstrate proficiency in calculating and controlling a gliding profile from cruising altitudes all the way down to landing on a runway. I argue that following the Airbus Training Standards, airline crews that completed an A320 type-rating course remain unprepared for a real ALL ENGINES FAIL critical situation, which is atypical, unfamiliar (Clewley & Nixon, 2019) and untrained.

From a flight-crew human factors perspective, applying the Airbus Golden Rules to control the aeroplane and managing the required procedures relies on mental processes that add considerably to workload. Jarvis et al. (2014) consider that the difficulty of a task and the time available to complete the task are two out of four general task factors that *directly* affect cognitive workload (Jarvis, 2010, as cited by Jarvis et al., 2014, p55). As pilots cannot 'buy' more time because the gliding time available is a function of the aeroplane altitude and can only run shorter as the aeroplane approaches the ground, the task of calculating and controlling the glide profile becomes critically important. If the pilots rely solely on the QRH gliding calculation guidance, which I argue is very difficult to operationalise, a significant increase in cognitive workload is foreseeable. This will affect the crew's ability to focus attention, which has implications for situational awareness[4] and the subsequent decision-making required to control the situation (Jarvis et al., 2014); therefore, the procedure design may *directly* impact the desired outcome. Are there any alternative ways that pilots could use to manage such a complex situation?

> Since it is impossible to reduce the *real complexity*, the alternative solution is to reduce the *perceived complexity* of the system by simplifying the information presentation. The reasoning is that if the system can be made to *look* simpler, then it will also be simpler to control. (Hollnagel & Woods, 2005, p.85)

I argue that pilots can use simplified *cognitive strategies* for mentally economical decision-making (Allspaw, 2015) that integrate existing simplified verbal knowledge that is not written anywhere in the form of judgment heuristics. Using these judgment heuristics can lead to satisfactory (good enough) solutions. "The obvious advantage of these mechanisms is that they save time and effort." (Jarvis et al., 2014, p.91) A satisfactory solution is better than an optimised one that "obviously takes a lot more time and effort, but importantly it may be beyond the capabilities of people in most complex situations" (Jarvis et al., 2014, p.90). I argue that this is an example of a desirable *simplicity-complexity trade-off* (Hollnagel & Woods, 2005, p.82).

I am not trying to suggest that judgment heuristics or simplified workflows could replace checklists or change the high-level priorities. I argue that during an ALL ENG FAIL situation, considering the potential effects of startle, surprise, and workload on pilots' cognitive capacity, the judgment heuristics as an addition to the manufacturer procedures may help the pilots from

---

[4] Situational Awareness (SA) - "refers to the operational behaviors that a pilot might exhibit as a result of his information processing abilities" (Moriarty, 2015, p.XXIV)

the high-level initial steps (*fly & navigate)* when they make their *initial navigational decision*, throughout the descent (*monitor and control* the glide path), all the way to landing and stopping on a runway.

While the probability of an ALL ENGINES FAIL event happening in real life is low, I argue that the conclusions drawn from such a clear-cut case can indicate salient directions both for procedure design and for further – and more fine-grained – research on pilot training methods.

2 Literature Review

The cockpit of an A320 is a complex socio-technical system, as it consists of interrelated and interdependent elements. The system agents are pilots, technology, procedures, environment, ATC, all joined to pursue safe air transport. Dynamic couplings create complexity as neither their goals, resources, nor constraints remain constant (Adriaensen, Patriarca, Smoker, & Bergström, 2019).

In this chapter, I refer to literature that links the object of this research – the Airbus A320 ALL ENG FAIL QRH procedure (Airbus, 2019d, ABN-19.01A) – with the various system agents in the context of an ALL ENGINES FAIL at cruising altitudes.

I consider a CRM perspective that connects the QRH procedure design with pilots' cognitive workload, situational awareness, and ability to make effective decisions. Next, I look at literature that discusses 'tacit knowledge' and judgment heuristics. I touch upon what Wilson & Sharples (2015) argue about Human Factors and Ergonomics (HF/E), and, finally, I connect all the elements drawing upon the Cognitive Systems Engineering (CSE) approach, as "a systems approach to phenomena that emerge at the intersection of people, technology and work" (Woods & Hollnagel, 2006, p. 13).

CRM training is regulated by the EASA Acceptable Means of Compliance (AMC) to Annex III - Part-ORO document (EASA, 2016) with the training programs detailed in the COMMISSION REGULATION (EU) of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 216/2008 of the European Parliament and the Council. (European Union, 2011) CRM courses theoretically cover human factors topics such as startle effect, stress & stress management, workload management, situational awareness, decision-making, and resilience development.

The Flight-Crew Human Factors Handbook (CAP 737) is a UK Civil Aviation Publication created by the Crew Resource Management Advisory Panel "to provide more focussed and applied practical CRM training guidance". (Jarvis et al., 2014) The document presents a practical view of the relationship between *workload*, *situational awareness*, and *decision making*. The following three sections clarify these concepts.

2.1 Workload

According to Jarvis (2014), the cognitive workload is "the amount of mental effort needed (and expended) to process information". The authors argue that "high workload is associated with increased errors, fatigue, task degradation, and poor performance" (Jarvis et al., 2014, p.55), and this is particularly important for pilots facing an abnormal or emergency situation on the flight deck, when the task load may suddenly change and increase.

Besides factors such as fatigue, level of arousal, and the duration of the task, Jarvis mentions the "'difficulty' of the task", the "number of tasks running in parallel (concurrently)", the "number of tasks in a series (switching from task to task)", and "the time available for the task (speed of task)". These four general task factors *directly* affect cognitive workload (Jarvis, 2010, as cited by Jarvis et al., 2014, p55), and subsequent situational awareness and decision-making processes.

2.2 Situational Awareness

In colloquial terms, situational awareness (SA) is referred to as "knowing what is going on" (Jarvis et al., 2014, p.71). Endsley (1995) argues that gaining situational awareness results from a three-step sequence: perceiving the information, comprehending it, and projecting the situation into the near future. While this view is widely embraced in airline CRM training, it is important to underline that SA is a dynamic and constantly updating process. This detail builds upon Neisser's (1976) perceptual cycle model (PCM) which "structures the interaction between a person's mental template (internal schemata) and the environment in which they work"(Plant & Stanton, 2015), and "has formed the foundation of contemporary theories of SA and has been applied to the explanations of accidents." (Plant & Stanton, 2016)

In this research, I use the term situational awareness, referring to "the operational behaviors that a pilot might exhibit as a result of his information processing abilities" (Moriarty, 2015, p.XXIV), and articulate it with the following elements (Gawron, 2008):

- pilots' understanding/knowledge of the energy state/environment/gliding distance, which implies the pilots' ability to perceive and process the information, and
- pilots' ability to anticipate or accommodate trends, which requires some degree of projection of the situation into the future.

These elements can be used as SA measurement tools (Gawron, 2008). Anticipating and accommodating trends may require aeroplane trajectory adjustments (direct inputs on the aeroplane controls) resulting from anticipatory decision-making processes based on SA. Such valuable insights into pilots' perceived SA can be used to assess the impact of adding judgment heuristics to the manufacturer QRH procedure and how this addition contributes to the overall management of an ALL ENGINES FAIL situation.

2.3 Decision Making

Jarvis et al. (2014, p.79) visualise the time and effort required to make various types of decisions using the simple continuum in Fig. 2:

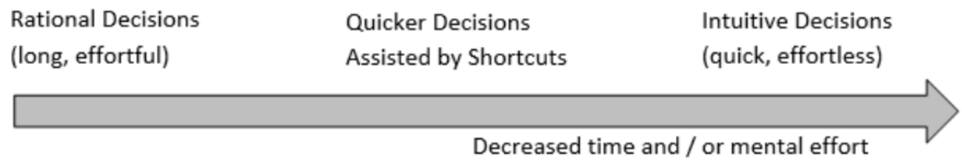


Figure 2. Simple continuum for decision types (Jarvis et al., 2014, p.79)

The authors argue that decisions require "reasoning and logic to make the most ideal choice" (p.80). Such decisions take a long time, require a high cognitive workload, and are structured: analysing the problem, generating options, balancing the pros and cons of each option, and finally choosing the best one. "In aviation, the most likely occasions when rational decision processes are attempted are *novel and/or complex situations*, *and when time is available* [emphasis added].” (Jarvis et al., 2014, p.82)

At the opposite end of the decision types continuum (Figure 2), Jarvis et al. place intuitive decisions. The authors argue that such decisions are based on Klein’s recognition-primed decision-making model (RPD), which “describes how decision makers use their experience to avoid painstaking deliberations” (Klein, 1993). Jarvis et al. argue that most decisions made on the flight deck fall into this category “because both crew-members are experienced enough to base choices on past experience” and are therefore quick and effortless (Jarvis et al., 2014, p.96).

Reflecting on an interview with A380 Captain Richard de Crespigny, Shorrock (2020) places the concept of Efficiency-Thoroughness Trade-Off (ETTO) (Hollnagel, 2009) at the core of the rational decision-making process. Shorrock concludes that during the management of a complex situation aboard an Airbus 380, de Crespigny and his crew made

> trade-offs between shorter-term and longer-term goals, between thoroughness and efficiency, between monitoring and acting, between compliance and creativity, between diagnosing components and understanding whole systems, between a focus on what wasn’t working and what was working, and between different kinds of risks. These trade-offs are relevant to normal operations, but become more critical in a crisis. (Shorrock, 2020)

Such an analysis required “a slower decision-making process . . . taking minutes or even up to two hours.” (Shorrock, 2020)

An ALL ENGINES FAIL situation is time-limited, yet essential navigational trade-offs must be made. According to Hollnagel & Woods (2005, p.169), four aspects of time can be identified in this case:

a) The total time available (TA) is a function of the aeroplane altitude, dictating the maximum gliding time and the maximum range (ground distance). In this situation, the gliding time available is a *critical constraint*.
b) The time needed for evaluation (T_E); the time required to determine the landing strategy
c) The time needed for the selection of a suitable landing spot (T_S)
d) Performance time (T_P) – the time for crew work; continuously calculating and adjusting the gliding distance to reach a chosen landing spot, ideally a runway.

The evaluation, selection, and performance tasks are referred to in this thesis as a single navigational element: the pilots’ *critical task.*

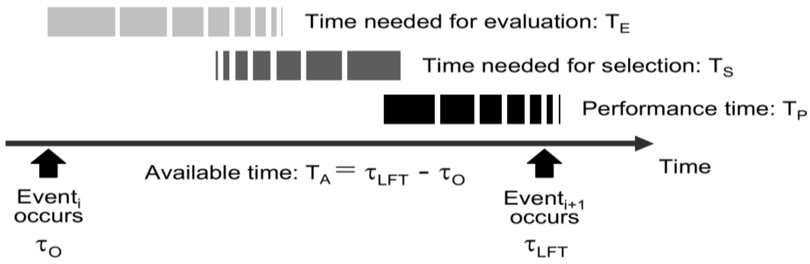


Figure 3. Temporal relations at work (Hollnagel & Woods, 2005, p.169)

As advised by the Airbus FCOM, using the information provided by the ECAM, "the flight crew should be able to rapidly assess the situation and determine their landing strategy if the engines do not relight." (Airbus, 2019a, PR-AEP-ENG P 5/24) In other words, pilots should quickly evaluate (during T_E) and select (during T_S) their landing spot.

Once the pilots chose a landing spot, it is essential to perform the appropriate navigational manoeuvres to get the aeroplane onto the desired profile (during T_P). Any uncorrected profile deviation can later lead to either undershooting or overshooting the runway. The closer to the ground the aeroplane gets, the more accurate the gliding profile control must be. This navigational part, the *critical task*, is most demanding on the pilots' cognitive resources.

The evaluation, selection, and performance processes are cyclic, as suggested by Neisser's (1976) perceptual cycle model. Pilots would constantly need to re-evaluate their situation, re-select the course of action, and adjust their actions/performance. This cyclicity is part of the Contextual Control Model (COCOM) (Hollnagel & Woods, 2005) and will be further discussed later in this chapter.

The time available to the crew to make their initial analysis and decision (T_E+T_S) is short and requires a rapid transition from rational decisions to quicker decisions. According to Jarvis et al., quicker decisions require using *shortcutting mechanisms,* which "become more prevalent as general task load increases, when the time and attention required for rational decision processes is limited." (Jarvis et al., 2014, p.91) This type of decision is depicted in the middle of the decisions type continuum (Figure 2).

After clarifying the key concepts of workload, situational awareness, and decision-making, the following two sections explain why the QRH procedure may be reasonably considered as falling short from structural and procedural design perspectives. Following that, I clarify the concept and the potential role played by judgment heuristics in improving task performance.

2.4 Time and control

The ability to make quick decisions and adapt the strategy to control the energy and trajectory is crucially important during glide management when the accuracy of the navigational trade-offs becomes more and more acute as T_P decreases when the aeroplane is approaching the ground.

What shortcutting mechanisms can pilots use at the onset of an ALL ENGINES FAIL situation so they can make effective altitude/speed/distance trade-offs considering the available time for the critical task?

According to the manufacturer guidance, they can use the estimated range information displayed on the ECAM to make an initial decision. After that, Airbus FCOM states, "the ALL ENG FAIL QRH procedure addresses all situations and provides all necessary procedure steps until the touchdown if the engines do not relight" (Airbus, 2019a, PR-AEP-ENG P 6/24) during TP.

Hollnagel and Woods (2005) argue that the "common basis of interface design" is the 'right-right-right' rule (the right information, in the right form, at the right time) (see section 7.6.1. below). From this perspective, the QRH procedure effectiveness is questionable due to its structural design. The navigational information provided in the QRH procedure, despite being technically correct (right information), is of little use because it is not presented in a form that pilots can efficiently process (right form), does not come at the right time, nor is effectively operationalisable under increasing pressure of decreasing time available (TP). Therefore, it has limited use to enable pilots to make adequate energy and trajectory predictions in order to control the situation.

Moreover, Hollnagel & Woods (2005) consider the relation of control mode dependency on time, where they analyse the "temporal characteristics of actions" (p.170), portraying four types of control modes ("which correspond to characteristic differences in the orderliness or regularity of performance" (p.146)), using *predictability* and *available time* as reference elements for their analysis:

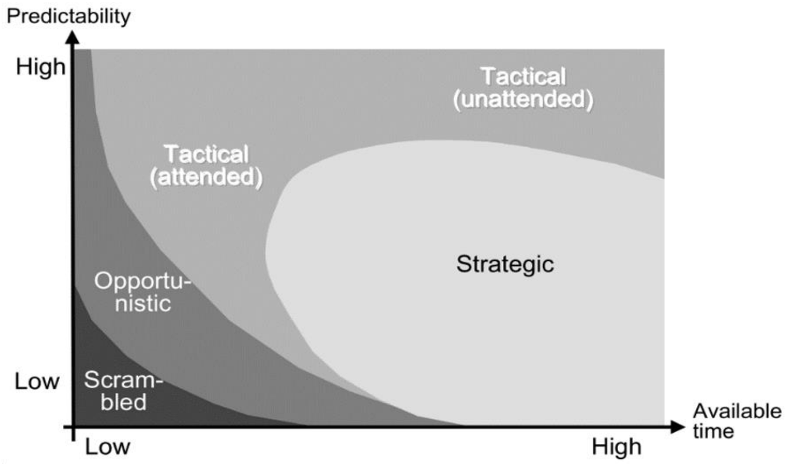


Figure 4. Main determinants of control modes (Hollnagel & Woods, 2005, p.161)

The control modes characteristics are:

Control mode	Number of goals	Subjectively available time	Evaluation of outcome	Selection of action
Strategic	Several	Abundant	Elaborate	Based on models/predictions
Tactical	Several (limited)	Adequate	Detailed	Based on plans/experience
Opportunistic	One or two (competing)	Just adequate	Concrete	Based on habits/ association
Scrambled	One	Inadequate	Rudimentary	Random

Table 1. Main Control Mode Characteristics (Hollnagel & Woods, 2005, p.148)

Based on this categorisation, I conclude that the QRH procedure induces the pilots into a *scrambled* control mode as the limited time is inadequate to process the information presented by the QRH procedure; hence, pilots can only make rudimentary trajectory predictions. They may need more time to evaluate the situation using the QRH navigational information, select a course of action, and perform the necessary trajectory corrections, than they have total time available. This situation may trigger a "trial-and-error type of performance" where "the choice of next action is basically *random* [emphasis added]" (Hollnagel & Woods, 2005, p.146).

Before discussing possible alternative shortcutting mechanisms that may enhance pilots' ability to control an ALL ENGINES FAIL situation at cruising altitude, a few procedure design considerations may be necessary.

2.5 Procedure design

The Airbus QRH procedure can also be characterised as an *abnormal checklist*, as according to Degani & Wiener (1990), it is intended "to aid the pilot during emergencies and/or malfunctions of the systems", to "serve as a memory guide", ensure that all critical actions are taken", "reduce variability between pilots", and "enhance coordination during high workload and stressful conditions". (Degani & Wiener, 1990)

The authors cite Drury et al. (1987) to argue that three factors need to be analysed when designing a checklist:

> The first is the hardware/software operating process which is the foundation for the entire task analysis. The second stage is the task classification and description which details the human task requirements and provides the information needed to perform the work. The third is the actual analysis, interpretation, evaluation, and transformation of the task demands based on the knowledge of human capabilities. (Drury et al., 1987, as cited by Degani & Wiener, 1990)

The Airbus A320 ALL ENG FAIL QRH procedure design (Airbus, 2019d, ABN-19.01A) may be based on an insufficient understanding of the required operational process and human task requirements. It does not effectively offer pilots the navigational information required to calculate and monitor the gliding profile – the critical task – in a manner that can be effectively interpreted and operationalised by the pilots within their foreseeable human capabilities. Under increased cognitive workload and critical task time pressure, the checklist design may trigger a series of undesirable human performance – cognitive – consequences for the pilots:

During T_P, pilots may try to speed up the gliding profile calculation process (requiring difficult and time-consuming QRH profile calculations), which may lead to profile errors, which under increasing time pressure (aeroplane approaching the ground) may add additional difficulty to the critical task. If the pilots do not have any alternative sources from which to get information, nor can they simplify the critical task, then "there is clearly a danger of a vicious workload circle beginning." (Jarvis et al., 2014, p.58) Reactively, on the spot, the "task difficulty is the driver that is least likely to be able to be reduced at the time; there is often no quick way to make a task less difficult". (Jarvis et al., 2014, p.60)

2.6 Alternative shortcutting mechanisms: judgment heuristics

To make an ALL ENGINES FAIL situation effectively manageable, it may be that the only *technical solution* is to decrease the difficulty of the critical task. It may require a proactive simplification of the procedure to a level commensurate with the foreseeable pilots' cognitive workload management abilities, incorporating well-thought and trained *shortcutting mechanisms* in the form of *judgment heuristics,* as suggested by Hollnagel & Woods (2005):

> The strategies or tricks used to compensate for a shortage of time can conveniently be discussed under two headings, one in terms of the technical solutions available and the other in terms of the heuristics that people use to cope with the temporal complexity. (Hollnagel & Woods, 2005, p.170)

Such judgment heuristics exist already but are not written anywhere. Passed on verbally as *tacit knowledge*, judgment heuristics are often seen as part of the broader colloquial concept of *airmanship*.

2.7 Tacit knowledge and heuristics

Tacit knowledge "allows the expert to identify exceptions, decide, operate, and communicate" (Katerinakis, 2019, p.5). Vaughan refers to tacit knowledge as "an intuitive cognitive process" (Vaughan, 2004), while Wilson & Sharples argue that tacit knowledge "should be seen as a form of knowledge that is more easily articulated in certain situations as opposed to others". (Wilson & Sharples, 2015, p.190)

The importance of considering the role of tacit knowledge in system design is addressed by de Vires & Bligård (2019). They locate its source within the actual performance of work and the practices it entails and question whether this type of knowledge can be "captured" or "rationalised" in an objective manner that is not sensitive to the experiences of those engaging in the relevant work. The importance of such "capture" of tacit knowledge and of being able to pass it on to others cannot be overstated in the case of

> safety-critical domains – such as aviation, nuclear, healthcare, offshore and maritime – successfully capturing how essentials such as monitoring and controlling (e.g. Praetorius & Hollnagel, 2014; van Westrenen & Praetorius, 2012, as cited by de Vries & Bligård, 2019) and the use of tacit knowledge (Mikkers et al., 2012; Praetorius et al., 2015, as cited by de Vries & Bligård, 2019) are performed is therefore a pressing challenge for system design (Hoffman & Lintern, 2006, as cited by de Vries & Bligård, 2019). (de Vries & Bligård, 2019)

Tacit knowledge plays an important role in developing judgment heuristics, which are essential cognitive strategies for mentally economical decision making (Allspaw, 2015) based on feedforward or anticipatory control (Hollnagel & Woods, 2005, p.137). They are possible alternative shortcutting mechanisms (Jarvis et al., 2014) that may reduce the critical task difficulty, which may free up pilots' cognitive capacity to manage the suddenly changed and increased cognitive workload and procedural task load.

2.8 Joint Cognitive Systems

As mentioned at the beginning of the chapter, the cockpit of an A320 is a complex socio-technical system consisting of pilots, technology, procedures, environment, ATC, etc., all together to pursue safe air transport. Wilson & Sharples (2015) argue that the human is still at the controls of any complex socio-technical system. The human's performance is influenced by the human's *abilities*, *needs,* and *limitations*. Successful products or work systems will usually show evidence that the *needs* of their users have been accounted for during design, implementation and operation. (Wilson & Sharples, 2015). The relation between the *abilities*, *limitations*, and *needs* of agents taking part in a socio-technical system is central to this research as it bridges the discussion from the individual crew level to a systemic level, where we can observe how the QRH procedure design – and adding judgment heuristics to it as a possible alternative design – can impact the outcome of the situation.

"The generation of alternatives, their characterisation, and finally the choice have each been the subject of much research in . . . human factors engineering. Yet it is only by considering them together, rather than as separate functions, that they make sense." (Woods & Hollnagel, 2006, p. 46-47) Cognitive Systems Engineering (CSE) is using the notion of co-agency to offer precisely this perspective: the pilots, the aircraft, the environment, the landing runway, the QRH procedure and the judgment heuristics all part of a single system, a Joint Cognitive System (JCS) (Woods & Hollnagel, 2006).

"For CSE the ability to maintain equilibrium or to be in control is paramount. This in turn requires the ability to make predictions or to use feedforward control" (Hollnagel & Woods, 2005, p.46)**.** In an ALL ENGINES FAIL situation, the pilots' ability to control and make predictions of the aeroplane trajectory may be directly influenced by the information given to them by artefacts such as the manufacturer procedure or the judgment heuristics.

2.8.1 Feedback & feedforward artefacts

"Control requires the ability to compensate for differences between actual and intended states. This in turn requires the ability somehow to sense, measure, or perceive the difference." (Hollnagel & Woods, 2005, p.136)

In the ALL ENGINES FAIL situation, sensing or perceiving the difference between the actual and the intended (operational engines) state is evident. At this point, measuring and compensating for differences requires a new reference point. Can the Airbus QRH procedure effectively offer such a reference point – intended profile – in the first place, and can the information provided by the procedure help pilots monitor, anticipate, and accommodate flight path trends promptly? The Joint Cognitive System framework can serve as a unit of measurement for the efficacy of QRH and judgment heuristics as feedback and feedforward artefacts in the glide management and control process.

> Feedback takes time, and if time is in short supply something must be done to reduce the demands. The solution is feedforward or anticipatory control, which can be defined as acting on an expected deviation or a disturbance but before it has happened. (Hollnagel & Woods, 2005, p.137)

In other words, my contention is that judgment heuristics may serve as feedforward artefacts, potentially allowing for better task performance under the severe time and psychological constraints of an ALL ENG FAIL situation. Using them, pilots may move from a scrambled to a tactical control mode (see section 2.4) to better achieve the system's goal to land and stop on an available runway.

The impact of judgment heuristics on the system's performance can be understood by using the Contextual Control Model (COCOM) (Hollnagel & Woods, 2005, p.147), which articulates the basic dynamics of control and illustrates the principle of the control modes (p.148).

2.8.2 Contextual Control Model (COCOM)

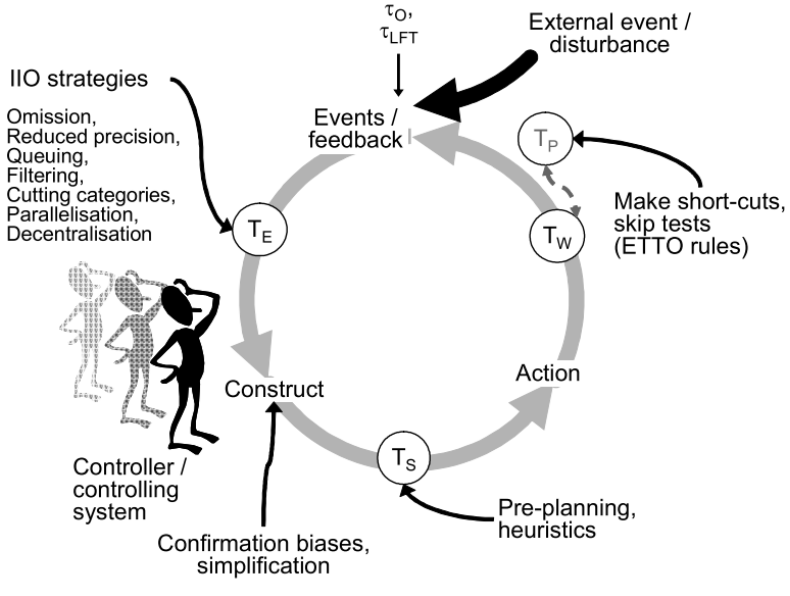


Figure 5. Human solutions to alleviate time shortage (COCOM) (Hollnagel & Woods, 2005, p.174)

> On a general level, the model shows how actions depend on the current understanding (construct), which in turn depends on the feedback and information (events) received by the system, which in its turn depend on the actions that were carried out, thereby closing the circle. (Hollnagel & Woods, 2005, p.147)

All the elements discussed until now find their place in the three interactive COCOM core elements: *action, construct, events/feedback*.

Following the onset of the *event,* the workload suddenly changes and increases. Pilots may face significant cognitive challenges: their cognitive abilities may significantly decrease, consequently increasing their needs for simplified and effective tools (commensurate with their contextual cognitive limitations (Wilson & Sharples, 2015)) that they can use to construct their situational awareness and help them make timely decisions that would dictate the actions that would have a direct impact on the system performance (Jarvis et al., 2014).

The impact of the QRH procedure and the judgment heuristics artefacts can be assessed during the time to evaluate (TE) at the *construct* step of the COCOM, where the pilots construct their understanding of the energy state/environment/gliding distance based on which they can anticipate and accommodate trends (Gawron, 2008; Jarvis et al., 2014; Moriarty, 2015). As discussed in section 2.4, the QRH procedure may induce pilots into a *scrambled* control mode, while the addition of judgment heuristics may help them reach a much more desirable *tactical* control mode (Hollnagel & Woods, 2005) using the heuristic information as a feedforward artefact, as discussed in section 2.8.1.

The pilot's subsequent *actions* on the aeroplane controls dynamically impact the aeroplane energy state and the gliding distance (Gawron, 2008). This process takes place during the time window (TW) allowed for execution/performance of actions (TP) (Hollnagel & Woods, 2005). Considering that any action on the controls will impact the speed, the altitude, and the gliding distance, the pilots will need to continuously trade-off speed, altitude, and gliding distance to keep the aircraft on the intended gliding profile.

Re-evaluating the aeroplane state and comparing it to the intended profile will offer the necessary feedback (or more effective *anticipated feedback*) (Hollnagel & Woods, 2005) to re-update the situational awareness; this will lead to a repetition of the cycle.

Finally, using a Joint Cognitive Systems approach (Hollnagel & Woods, 2005), the efficacy of the research object – the Airbus A320 ALL ENGINES FAIL QRH procedure – on the JCS performance can be assessed. The impact of adding judgment heuristics to the JCS can also be assessed by comparing the performance of two JCSs, one with and one without added judgment heuristics.

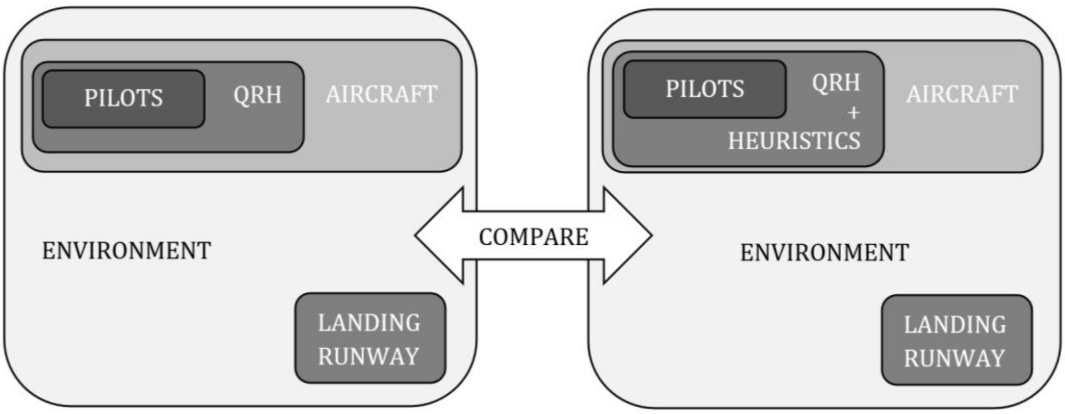


Figure 6. Comparative research of Joint Cognitive Systems with and without the use of heuristics

Observing how pilots balance between using the complex QRH navigational information and the much more simplified heuristic information and how their choices impact the performance of the JCS can offer a good practical indication of procedural Simplicity-Complexity Trade-Off (Hollnagel & Woods, 2005, p.82).

The invitation to this experimental comparative research is formulated in the following question:

3 Research Question

How does the manufacturer QRH procedure contribute to the pilots' management of navigation in an ALL ENGINES FAIL situation at cruising altitude on board an Airbus A320, and can judgment heuristics that integrate tacit knowledge improve the task performance and the desired outcome?

4 Methodology and Methods

To see how the use of judgment heuristics impacts the management of an ALL ENGINES FAIL at cruising altitudes simulation, we first need to observe how the situation is managed without heuristics. The observations take place in Airbus A320 simulators flown by volunteer airline pilots qualified on the Airbus A320.

4.1 Methodology

This research draws upon an experimental design perspective, a One Group Pretest-Posttest design (Campbell & Stanley, 1963, p.7) which can be expressed in the following form:

O1 X O2

An experimental variable (X), represented by judgment heuristics, is introduced, briefed, and practised between two observed simulations (O1 and O2). By comparing O1 with O2, an eventual difference caused by X can be assessed. While this methodology may be subject to a series of accuracy questions regarding internal and external validity (Campbell & Stanley, 1963), it is suitable to assess if X causes a rough negative, neutral, or positive change on O2.

A more robust option would have been to use a One Group Pretest-Postest Control Group design (Campbell & Stanley, 1963, p.8), covering most of the accuracy oriented questions related to the internal and external results validity, particularly the potential effect of skilled learning, when pilots improve their performance by the simple repetition of the same scenario.

R O1 X O2

R O1 O2

Unfortunately, researching during the pandemic raises significant limitations in terms of pilots availability. I deliberately chose not to use a control group to keep the logistic workload manageable. The significance of the results obtained without using a control group is tested using paired samples t-tests (Ross & Willson, 2017, p.17).

This research is underpinned by a Joint Cognitive Systems approach (Hollnagel & Woods, 2005), where the unit of analysis is the flight-deck work system (which will be observed), and the object of the research is the Airbus A320 ALL ENG FAIL QRH procedure (Airbus, 2019d). By comparing observations 1 and 2, it is possible to determine if judgment heuristics (the experimental variable), as a feedforward artefact (Hollnagel & Woods, 2005) in addition to the Airbus QRH procedure, affect task performance.

4.2 Methods

This research uses qualitative and quantitative methods: document analysis, structured interviews, simulations, and questionnaires.

4.3 Experiment description

This experiment is divided into three phases: pre-simulation, simulation, and post-simulation, as depicted in Figure 7.

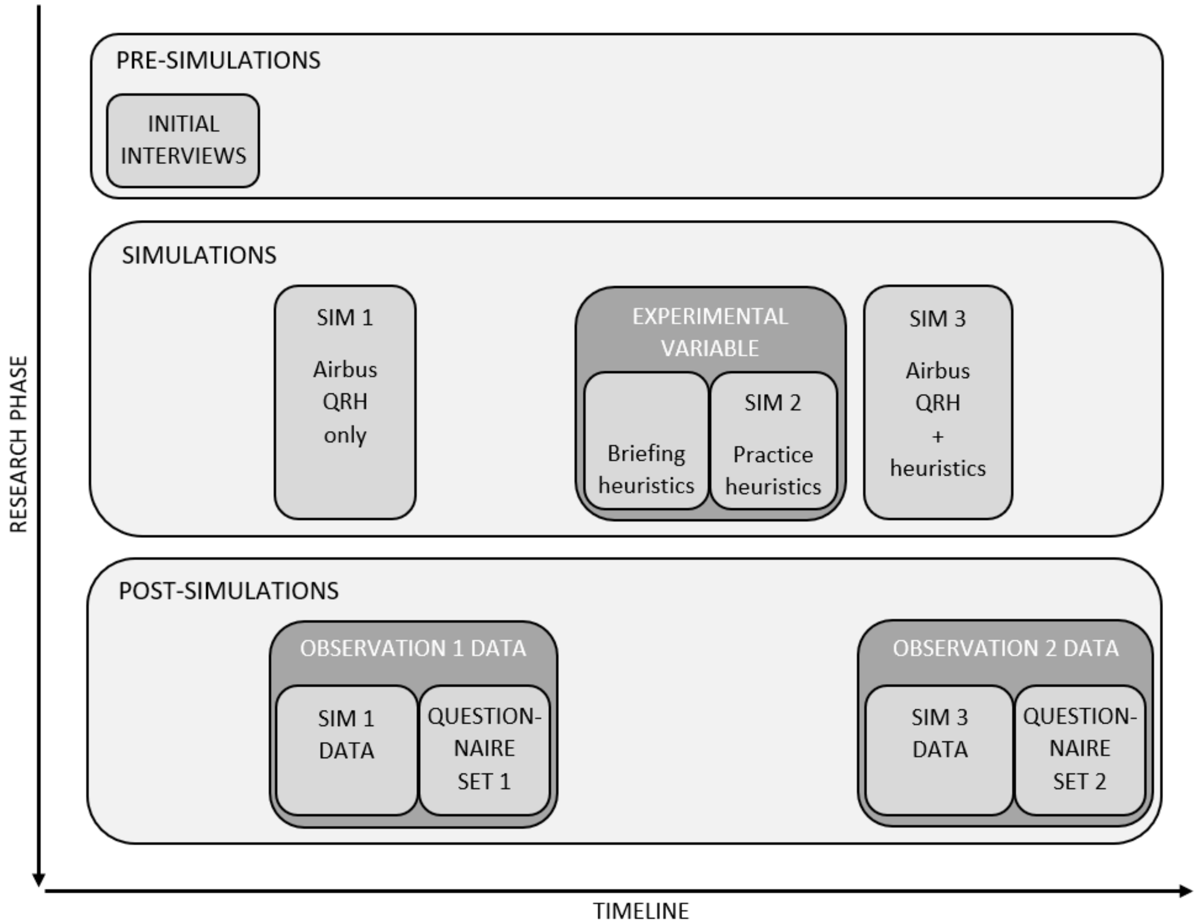


Figure 7. Experiment description graph

4.3.1 Pre-simulations

Before the simulations, the participants must answer three questions as part of an initial structured interview designed to assess their familiarity and experience using simplified rules-of-thumb to manage complex failures.

4.3.2 Simulations

Following the interviews, three simulations take place:

1. Simulation 1 is counted as Observation 1 (O1). It is run without interruptions, and pilots use only the Airbus A320 QRH procedure.
2. The experimental variable (X) – a set of judgment heuristics – is briefed following simulation 1 and practised during simulation 2. Simulation 2 does not count towards the research.

3. Simulation 3 is counted as Observation 2 (O2). It is run without interruptions, and pilots use the Airbus A320 QRH procedure, and optionally they can use the practised judgment heuristics.

4.3.3 Post-simulation data collection and analysis

The first and third simulation retrieved data results are compared with reference profiles derived from the Airbus QRH and the heuristics studied in this research. After the first and the third simulations, the crews are asked to fill identical questionnaire sets designed to measure the impact of judgment heuristics on their perceived Situational Awareness, Workload, and Decision Making (Gawron, 2008). The results are presented in tabulated form.

The compared simulation and questionnaire results indicate the impact of judgment heuristics on the JCS (Hollnagel & Woods, 2005).

4.4 Data collection

4.4.1 Analysis of documents

4.4.1.1 AIRBUS A320 documents.

The manufacturer documents offered to the A320 pilots are the Aeroplane Flight Manual (AFM), Flight Crew Techniques Manual (FCTM), the Flight Crew Operations Manual (FCOM), the Minimum Equipment List (MEL) and the Quick Reference Handbook (QRH). These sources are always available in paper or electronic format. The QRH contains the ALL ENG FAIL procedure that the pilots use during the simulations and is presented in Appendix 1.

There are many other sources of complementary information. I consider the AIRBUS Worldwide Instructor News (WIN) phone/tablet application, where numerous video tutorials are offered by AIRBUS instructors on various operational topics, the Flight Operations Briefing Notes – CRM Aspects in Incidents/Accidents, the Flight Operations Briefing Notes – Human Factors Aspects in Incidents/Accidents, and the Airbus Safety First training article – Preparing Crews to Face Unexpected Events. (Airbus, 2004b, 2004a, 2015, 2019a, 2019c, 2019d; Charalambides, Tyrrell, & Norden, 2017; Woods & Sarter, n.d.)

4.4.1.2 Other manufacturers documents

The Bombardier CRJ 900 (Bombardier, 2019) and BAE AVRO 146RJ (British Aerospace, 2007) ALL ENGINES FAIL procedure offer valuable comparative insights into procedure design. These are discussed using JCS feedback, feedforward, and timing effectiveness considerations. A comparison is made with the Airbus QRH procedure and with the judgment heuristics.

4.4.2 Initial interviews

During the initial structured interview, the pilots were individually requested to answer three questions before the start of the research:

1. During your formal and informal airline training, have you ever been taught simplified calculations (rules-of-thumb) that were not written anywhere in the company or manufacturer manuals, knowledge passed to you verbally? Can you please give examples?

2. If yes, how did the use of such simplified rules contribute to your flight management in normal and/or abnormal situations? Please give one or more examples.

3. Looking at the QRH ABN content list, which situations would you describe as *most critical* in terms of time available, loss of automation, descent profile, or any other?

I designed these questions to understand the participants' previous knowledge and experience using simplified rules to manage complex failures and how this prior knowledge may impact their abilities to manage the simulated situation. Additionally, the answers to the third question may indicate valuable directions for future research.

The interview protocol is detailed in appendix 6, together with the interview transcriptions. The transcriptions are analysed using Content Analysis, and the results are summarised in tabulated form.

4.4.3 Simulations

The primary artefacts used for the research are a certified fixed-base A320 simulator operated by the Wizz Air Pilot Academy at the Wizz Air Training Centre in Budapest, and a fixed-base, non-certified A320 simulator, operated by the Flight Experience (FlightX) Company in Cluj-Napoca, Romania (www.FlightX.ro). The decision to use this second simulator is financially and logistically based. I partly own this business, and it was, therefore, free of charge for unlimited use. My access to the Wizz Air simulator was limited by the time I was in Budapest for training duties and the available simulator slots. The technical details of both simulators are presented in appendix 2. The simulator scenarios, reference profiles, and protocols are detailed in chapter 5 of this dissertation.

The comparative data obtained from the experimental simulations have been tabulated and used to generate visual analytical summaries that show how the incorporation of judgment heuristics has impacted the studied JCS (pilots, QRH, heuristics, aeroplane, environment, runway) as a feedforward artefact (Hollnagel & Woods, 2005).

4.4.4 Questionnaires

The pilots were requested to individually fill out an identical set of questionnaires following simulation 1, using only the Airbus QRH, and following simulation 3, using Airbus QRH + judgment heuristics. The questionnaire aimed to measure the pilots' perceived Situational Awareness, Workload, and Decision Making using the following rating scales (Gawron, 2008):

- China Lake Situational Awareness Rating Scale to measure Situational Awareness
- Bedford Workload Scale to measure Workload
- Modified Cooper-Harper Rating Scale to measure Decision-Making

These rating scales generate valuable insights into the pilots' perception of important cognitive elements that may be impacted by the effects of sudden change and an increase in workload. The impact of the judgment heuristics on pilots' perceived management abilities can be measured by comparing the results of the questionnaires.

The China Lake Situational Awareness Rating Scale measures three sub-components:

1. knowledge of energy state/environment/gliding distance
2. ability to anticipate or accommodate trends
3. shedding of tasks

These measurements add valuable human factors insights that a) glimpse into the pilots' cognitive abilities and limitations under the sudden increase of task-load (Jarvis et al., 2014; Neisser, 1976; Wilson & Sharples, 2015), and b) can be used in conjunction with the JCS Contextual Control Mode (COCOM) analytical framework to see how feedback and feedforward artefacts impact the work system (Hollnagel & Woods, 2005).

The Bedford Workload Scale and The Modified Cooper-Harper Rating Scales results offer insights into the pilots' perceived ability to manage the situation. They can indicate how pilots, under time pressure, choose to use judgment heuristics to prioritise high-level goals over detailed and complex procedural items, a practical application of simplicity-complexity trade-off (Hollnagel & Woods, 2005, p.82).

Appendix 4 offers detailed information on how the questionnaires have been calibrated and used.

4.5 Research ethics - information, consent, and confidentiality

Important ethical considerations have been addressed with the volunteer pilots participating in this research. Their written consent was obtained. As stated on the Lund University website (https://www.researchethics.lu.se), the participants received and understood relevant information, in accordance with the Ethical Review Act:

- "The overall plan for the research,
- the purpose of the research,
- the methods that will be used,
- the consequences and risks that the research may entail,
- the person responsible for the research,
- that participation in the research is voluntary, and
- that the research volunteer has the right to terminate his or her participation at any time." (Lund University, 2019)

The personal data collected for analysis was anonymised and was related only to rank (first officer, captain, instructor, examiner) and experience (total flight hours and flight hours on the A320). The crew composition for each simulation was kept confidential. The research paper does not reveal any names, genders, nationalities, or any other aspects that would require an ethical review following the Lund University and Swedish Ethical Review Authority requirements (Lund University, 2019). All the data has been stored on a separate external hard drive.

5 Research Protocol, Simulation References & Scenarios

This research aims to see how judgment heuristics (the experimental variable), as an addition to the Airbus A320 QRH procedure (the object of this research), impact the outcome of a Joint Cognitive System (pilots, Airbus A320 aeroplane and procedures, environment, and available runways) (Hollnagel & Woods, 2005) following an ALL ENGINES FAIL situation at cruising altitude. This requires a simulation environment that would create the conditions to measure the delta between two simulations and their reference profiles. Observing the impact of the experimental variable as much as possible in isolation has been an important factor that needed to be considered when designing the research protocol and simulation scenario.

Importantly, in real life, the pilots may perceive an ALL ENGINES FAIL situation as "a flight condition that is confusing, sudden and potentially life threatening" (Moriarty, 2015, p.66). Such conditions may have "an immediate and sustained impact" on pilots' abilities to manage cognitive workload and make decisions, as "all mental capacity becomes focussed on the threat and/or the escape from it" (Jarvis et al., 2014, p.64), triggering possible startle and surprise effects. Startle is defined as "a physiological effect to a sudden, intense, or threatening stimulus", whereas "surprise is an emotional and cognitive response to unexpected events that are (momentarily) difficult to explain, forcing a person to change his or her understanding of the situation" (Foster & Keane, 2015; Meyer, Reisenzein, & Schuetzwohl, 1997; Schuetzwohl, 1998; Teigen & Keren, 2003, as cited by Landman et al., 2017a).

In this chapter, I explain how the simulation scenario and the research protocol have been designed to minimise the potential effects of startle and surprise on pilots' cognitive capacity or the eventual impact of other variables such as weather conditions or air traffic control instructions.

I will also explain how I have derived two separate reference profiles (Airbus QRH and heuristics) and their associated measurement points to assess the altitude/distance/ speed differences between the actual and intended reference gliding profiles.

"Control requires the ability to compensate for differences between actual and intended states. This in turn requires the ability somehow to sense, measure, or perceive the difference." (Hollnagel & Woods, 2005, p.136) It is important to emphasise that the research uses the simulation data to measure and compare the performance of the JCS and uses the questionnaires ratings to measure and compare pilots' perception of situational awareness, workload, and decision-making (Gawron, 2008).

The performance of the JCS is assessed by comparing two separate sets of differences (deviations) of actual profiles (SIM 1 and SIM 3) from two separate intended profiles, the Airbus QRH derived profile (used for SIM 1), and the heuristics derived profile (used for SIM 3).

A visual summary of how the retrieved data is referenced and compared is presented in Figure 8 below:

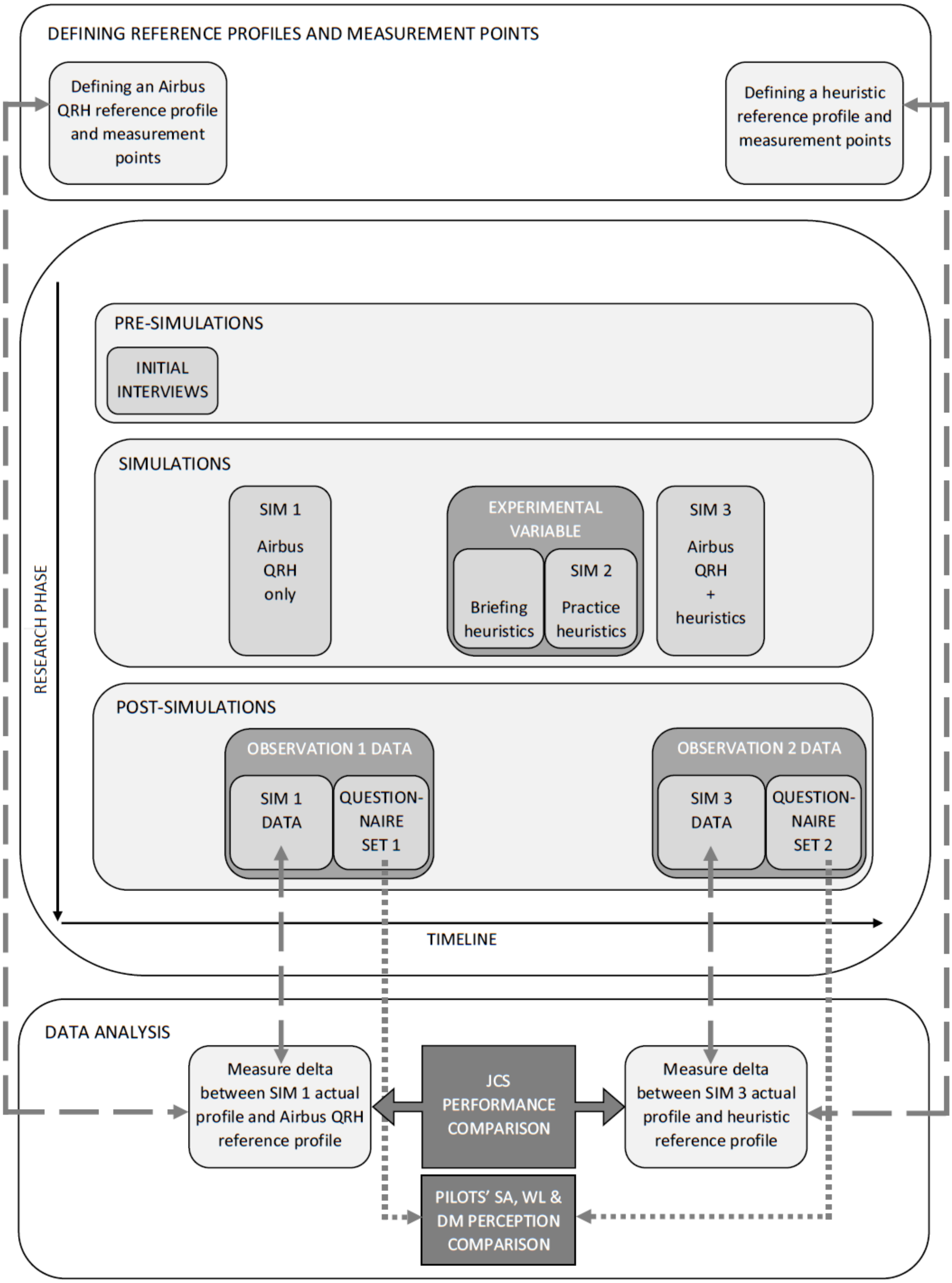


Figure 8. Data analysis; reference and comparison summary

5.1 Simulation scenario

The simulations were conducted using an Airbus A320 setup with IAE engines, at 63 tons, including 5 tons of fuel on board (the equivalent of more than 2 hours' flight time). The wind was calm, the sky was clear, it was daytime, and the temperature and barometric pressure were standard, according to the International Standard Atmosphere (ISA) (ISO, 1975). There was no weather variation during the simulations.

The initial position for the start of the simulation was set at Flight Level[5] (FL) 350, between Vienna and Budapest, South of Bratislava, as detailed in Appendix 3. The engines failed one by one at short time intervals, and pilots could not restart them. The simulator operator answered all the radio and cabin calls, taking the Air Traffic Controller (ATCO) and Senior Cabin Attendant (SCA) role.

If the crew requested radar vectors, the simulator operator cleared the crew to self-position for any desired runway in Vienna, Bratislava, or Budapest, to avoid any interference with the pilots' navigational profile calculations and decisions.

The crews used two printed Wizz Air QRH 'ALL ENG FAIL' procedures, version from 4 September 2019 (Airbus, 2019d, ABN 19.01A). This procedure is presented in appendix 1.

Each simulation took approximately 30 minutes.

5.1.1 Plotting the flight path and extracting the simulation data

The final plot of the simulation profile is inferred from multiple sources, depending on the simulator that was used. Detailed information about this process is presented in appendix 3.

5.2 Research protocol

The following research protocol allowed me to conduct this research following the Lund University requirements and ethical considerations:

1. All contacted pilots have expressed written consent to take part in the research. They were sent a briefing package in the form of a PDF file containing links to:

   a) A welcome introductory video
   b) Information regarding the ethical research considerations following Lund University's research ethical requirements presented on the Lund University website: https://www.researchethics.lu.se, for which explicit consent was requested.
   c) An online pilot data sheet where each pilot filled out the experience data.
   d) A video in which I brief the research structure and flow.

[5] Flight Level (FL) 350 = 35000 feet above mean sea level when the pressure at sea level is 1013.2 hPa.

e) Access to an online interview platform where the pilots recorded their answers to the three questions constituting the initial interview.
f) A video where I explain the rating scales (Gawron, 2008) that were used in the questionnaires that would follow simulations 1 and 3.

The briefing package contained PDF versions of all the rating scales used for the questionnaires and the table of contents of the QRH ABN chapter (Airbus, 2019d, ABN 19.01A), which was needed to answer question number three in the online interview. These documents are detailed in appendix 4. The package also contained the exact version of the ALL ENG FAIL QRH procedure (Airbus, 2019d, ABN 19.01A) used during the simulations.

2. When the pilots arrived at the simulator venue, they were handed the printed versions of the rating scales and, if needed, further clarification was given. They received the printed version of the ALL ENG FAIL QRH procedure. The pilots were briefed in detail when and where the failure will occur to minimise the potential effects of startle and surprise on crews' cognitive capacity (Jarvis et al., 2014; Landman et al., 2017a; Moriarty, 2015; Rankin et al., 2016; Rankin et al., 2013), They were also reminded how the primary and additional tasks were defined:

   Primary Task:

   - To successfully land and stop the aeroplane on a runway
   - PF: control the energy and keep it on a gliding profile that would enable a successful landing on a runway
   - PM: perform all ECAM and QRH items

   Additional Tasks:

   - PF: communicate with ATC, SCA and PAX and MONITOR PM's actions (ECAM/QRH)
   - PM: assist PF with calculating & monitoring the descent profile, configuring the aeroplane for landing, and with required callouts to the cabin

   Pilots were allowed sufficient time to discuss and familiarise themselves with the QRH procedure, and when they felt ready, they were invited to proceed in the simulator.

3. In the simulator, the aeroplane was pre-positioned on the threshold of Runway (RWY) 11 in Vienna. The pilots performed a normal take-off and continued flying on the runway heading until reaching 40NM DME[6] from VIE RWY 29. At this point, the position was frozen to save time; they were electronically climbed to FL 350. This process was repeated for each simulation, partly due to the set-up limitations of both simulators, but mainly to allow the crew to mentally enter 'flight mode' following a typical sequence (take-off, climb, cruise).

[6] Distance Measuring Equipment (DME) is a navigational beacon enabling pilots to measure their distance from that beacon.

4. SIMULATION 1: the simulator was unfrozen when the pilots reported ready. Engines failed one by one, and the crew had to manage the situation using only the Airbus QRH ALL ENG FAIL procedure (Airbus, 2019d, ABN 19.01A). The simulation was conducted without interruptions.

5. After SIMULATION 1 was completed, the pilots were requested to use their mobile phones and follow an online link to QUESTIONNAIRE SET 1, where they had to rate their perceived Situational Awareness, Workload, and Decision-Making (Gawron, 2008).
6. HEURISTIC BRIEFING. The crews in Cluj-Napoca were briefed remotely by me through a recorded video that was played on a large screen TV in the FlightX briefing room. The crews in Budapest were briefed live by me, using a whiteboard in a Wizz Air Training Centre briefing room. I have presented the same information in the live briefings as well as in the recorded briefings. No additional checklist was produced.

7. SIMULATION 2 was used for practising the briefed heuristics. Following the same take-off and positioning sequence described at point 3, the crews were guided on how to practically apply the heuristics to calculate and control the glide after the failure onset. This simulation was occasionally interrupted for clarification purposes. The guidance offered was strictly limited to the mental calculation of distance and altitude without offering any decision suggestions.

8. SIMULATION 3: following the same take-off and positioning sequence described at point 3, the simulator was unfrozen when pilots reported ready. They had to manage the situation using the Airbus QRH procedure (Airbus, 2019d, ABN 19.01A) and judgment heuristics. This simulation was conducted without interruptions.

9. After SIMULATION 3 was completed, the pilots were requested to use their mobile phones and follow another online link to QUESTIONNAIRE SET 2. According to their perception during the simulation, they had to re-rate their Situational Awareness, Workload, and Decision-Making (Gawron, 2008). QUESTIONNAIRE SET 2 contained identical rating scales as QUESTIONNAIRE SET 1.

5.3 Reference profiles and measurement points

Considering that the Airbus QRH and the studied judgment heuristics are presented differently, two reference profiles had to be defined to allow deviation measurements of various simulations profile parameters. The first reference profile had to be derived following the Airbus A320 QRH ALL ENG FAIL (Airbus, 2019d, ABN 19.01A) procedure analysis, and the second was derived from the studied judgment heuristics. From these reference profiles, I have extracted the measurement points used to compare the simulation profiles. These measurement points are essential elements for this research and will be explained in this sub-chapter. Importantly, SIMULATION 1 was referenced to the Airbus QRH derived reference profile, while SIMULATIONS 2 and 3 were referenced to the heuristics derived profile. The study compares the magnitude of deviations from the associated reference profiles.

5.3.1 The A320 QRH procedure analysis

When looking at the Airbus A320 ALL ENG FAIL QRH procedure (Airbus, 2019d, ABN 19.01A), the following discussion is based on two important assumptions:

1. The procedure is designed to offer step-by-step guidance to relight the engines, if possible
2. If engines cannot be restarted and if airports are available and within the estimated gliding range, the procedure will offer effective navigational guidance to the pilots so they may ideally land on a runway.

This research aims to see how the pilots manage a glide following all engine failure and land and stop on a reachable runway; hence, the second assumption is paramount. It is essential to look at this procedure to understand how I derived a coherent descent profile and the reference points based on which the simulations were analysed.

The Airbus QRH procedure (Airbus, 2019d, ABN 19.01A) does not present a coherent gliding profile. It offers separate gliding information for three different flight conditions: 280 KT, Green Dot speed, and landing configuration.

The first glide calculation information starts at step 6 in the check list:

“GLIDING DISTANCE 2 NM/1000 FT” (p. ABN 19.01A)

Two pages later in the checklist, below FL200 with APU running and flying at the Green Dot speed, the calculation changes to:

“GLIDING DISTANCE AT GREEN DOT: 2.5NM/1000FT” (p. ABN 19.03A)

Two pages down the checklist, if a forced landing is anticipated (not ditching) for the final approach:

“DESCENT SLOPE (CONG2, L/G DOWN) 1.6NM/1000FT” (p. ABN 19.05A)

For an easier understanding, I have visually depicted these *disconnected* pieces of information in Figure 9:

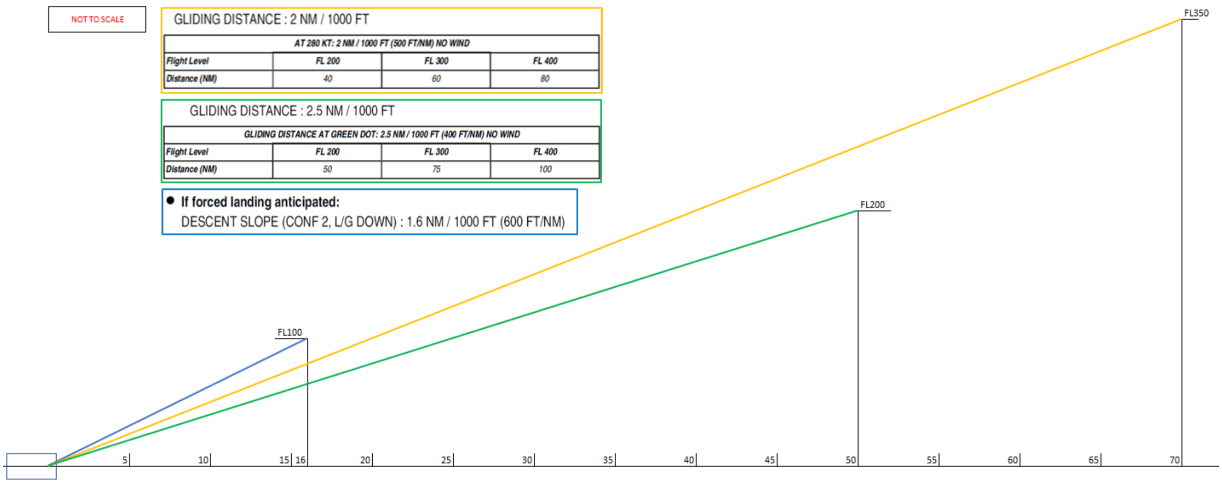


Figure 9. QRH derived descent profiles diagram (Airbus, 2019d)

With such *disconnected* pieces of information, with deceleration and configuration segments not considered, I argue that the procedure offers limited support for pilots to calculate and monitor their gliding profile. I have contacted Airbus to request more details about the procedure design, but I have not received an answer.

5.3.2 Deriving a connected Airbus A320 QRH profile

To create a *connected* reference gliding profile from FL350 based on the QRH procedure information, assuming that the aeroplane is already at 280 KT at FL350, we need to decide the following:

a) When and how to transition from 280 KT to green dot speed
b) When and how to transition from green dot speed to landing configuration

I have derived these deceleration segments based on my real aeroplane and simulator experience. Generally, for level deceleration segments, I was taught to use 1NM/10KT deceleration in clean configuration with engines running at idle thrust and double that rate with speed brakes or gear down. In the simulation scenario, the aeroplane has a Gross Weight of 63 tons. Interpolating the QRH procedure performance tables, we can obtain:

- Green dot speed at or below FL200 = 206 KT (Airbus, 2019d, ABN 19.03A)
- VAPP = 166 KT (Airbus, 2019d, ABN 19.04A)

Having defined these two necessary operational speeds, we can roughly estimate the deceleration segments:

a) 280 KT to 206 KT (green dot) in a 7,4NM level flight segment at FL200 if the engines would be running at idle power, providing idle thrust. In our simulation, however, the engines are windmilling and therefore may be creating additional drag. To be conservative in this case, based solely on my estimation, I subtract 1/3 of this deceleration segment and round it up to 5NM.
b) 206 KT (green dot) to VAPP 166 KT in a 2NM level flight segment at 3000ft AAL with gear down

In Figure 10, I attempt to visualise a *connected* gliding profile derived from the A320 QRH information:

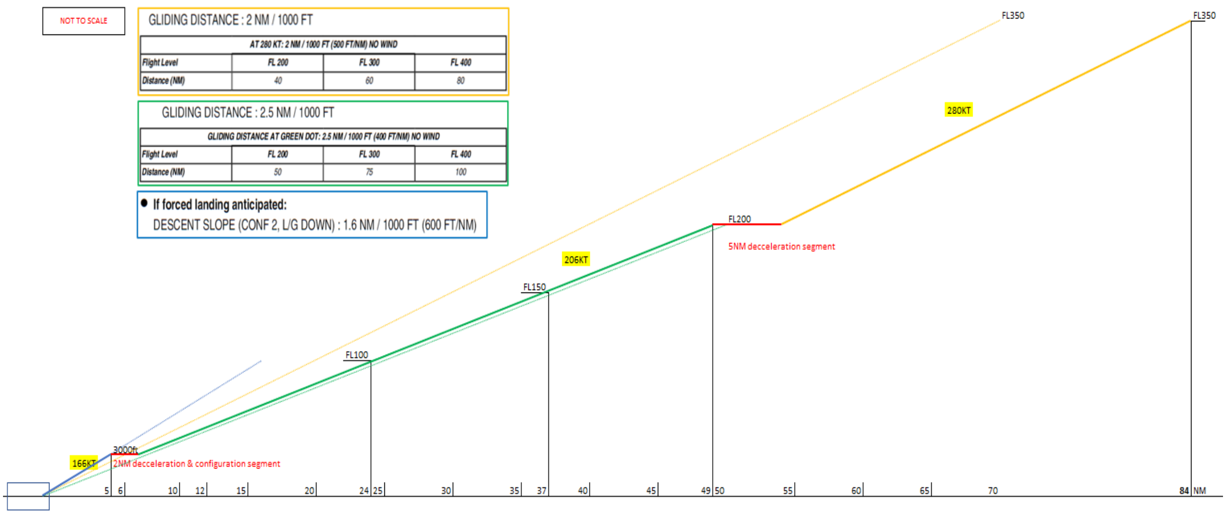


Figure 10. QRH derived gliding profile

Finally, to measure the deviations of simulation profiles flown using only the Airbus QRH procedure, I have chosen the following altitude/distance/speed reference points:

ALTITUDE/FL	DISTANCE	SPEED
FL350	84 NM	280 KT
FL200	49 NM	206 KT
FL100	24 NM	206 KT
3000 FT	5 NM	166 KT
50 FT	0 (AT THRESHOLD)	166 KT

Table 2. Airbus QRH derived profile - measurement points

5.3.3 The heuristic profile

Quite a few years ago, during one of my recurrent A320 simulator briefings run by a senior British examiner, I was presented a simplified ‘rule-of-thumb’ to calculate and monitor an ALL ENG FAIL descent profile:

‘Below FL200, take our altitude (thousands of feet) and multiply it by two to get your distance. Your target is to be at 6000ft 12NM out when your aiming point should be the far end of the runway. Around 3000ft lower the gear. The aeroplane will ‘sink’ nicely in the touch-down zone.’ This is not an exact quote. It is what I remember.

This heuristic using a simple rule to calculate and monitor their gliding profile for a straight-in approach can be summarised in the following formula:

Altitude (thousands of feet) x 2 = Distance (NM)

This approach seems to be making a rough average between the three types of calculation offered by the Airbus QRH:

(2+2.5+1.6)/3NM per 1000ft descent = approximately 2NM/1000ft

This is a simplified and incorrect average, as the times spent in descent at high speed, at green dot speed and on the final approach are not equal. However, it is conservative. A significant part of the descent, below FL200 to configuring for final approach, is spent at green dot speed, where Airbus QRH estimates 2.5NM/1000ft, which is more than what the heuristic is saying. During the glide at green dot speed, this excess of energy can be managed using speed brakes and/or extending the landing gear earlier.

Importantly, the heuristic assumes that the transition from green dot speed to landing configuration is done in continuous descent, without a level-off segment, as pilots usually do in normal operations, preferring a constant descent approach.

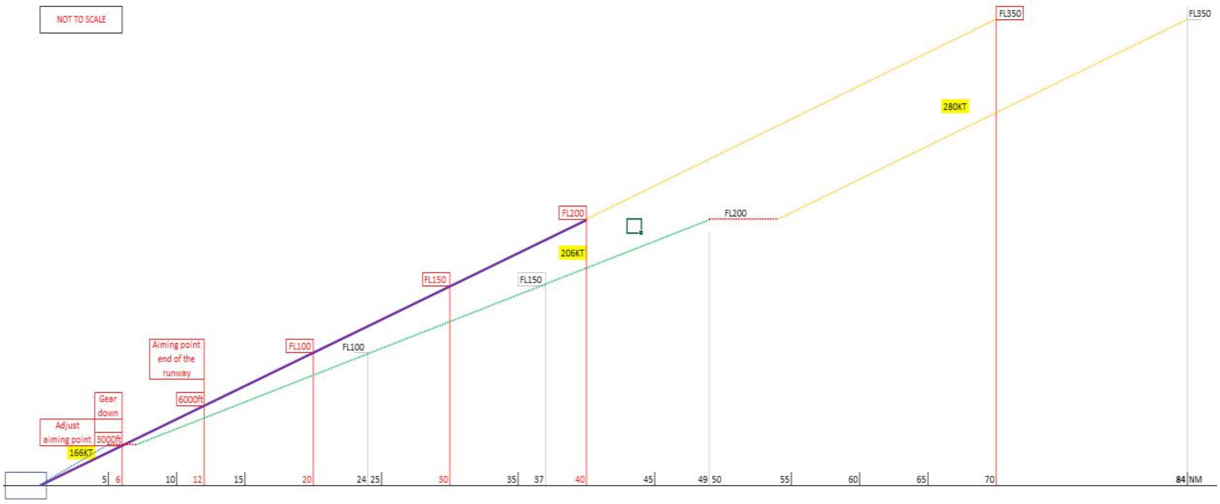


Figure 11. Heuristic gliding profile below FL200 compared to the Airbus QRH profile

The heuristic incorporates information on when to lower the gear and where to choose the visual aiming point. It uses the 6000ft/12NM 'gate' where, on a typical straight-in approach in visual meteorological conditions (VMC), the pilots would be able to see the runway. At this point, the pilots are advised to aim for the far end of the runway, which is counter-intuitive, until they reach 3000ft/6NM. Around this point, they should lower the landing gear while maintaining the gliding ratio of 2NM/1000ft. With the additional drag, the aeroplane would start decelerating towards VAPP. In the final stages of the approach, the pilots intuitively adjust their aiming point while prioritizing maintaining a high enough approach speed, ideally the VAPP.

The heuristic discussed is most useful in a straight-in approach at and below FL200 (as depicted in Figure 11). At this point on the descent, the aeroplane is already flying at or close to the green dot speed. The heuristic enables the pilots to quickly know if they are high or low on their profile, hence increasing their ability to monitor and accommodate trends (Gawron, 2008; Hollnagel & Woods, 2005).

The heuristic proposes a glide of 2NM/1000FT while flying at green dot speed (206 KT for the simulated weight), which is the same as the Airbus QRH data for flying 280 KT.

We can see that the heuristic profile is almost 20% more conservative than the QRH profile. From FL200, the QRH derived profile estimates 49NM gliding distance, and the heuristic profile estimates 40NM. Managing the extra energy is achievable by deploying the speed brakes.

We can define a heuristic gliding reference as follows at and below FL200:

ALTITUDE/FL	DISTANCE	SPEED
FL200	40 NM	206 KT
FL150	30 NM	206 KT
FL100	20 NM	206 KT
6000 FT	12 NM	206 KT
3000 FT	6 NM	166 KT
50 FT	0 (AT THRESHOLD)	166 KT

Table 3. Heuristic derived profile - measurement points

While this heuristic straight-in approach can work in still wind or with some headwind conditions, in a tailwind condition, it may become very challenging to maintain the profile without excessive acceleration. In such a case, there is a circling approach that can be used (Figure 12).

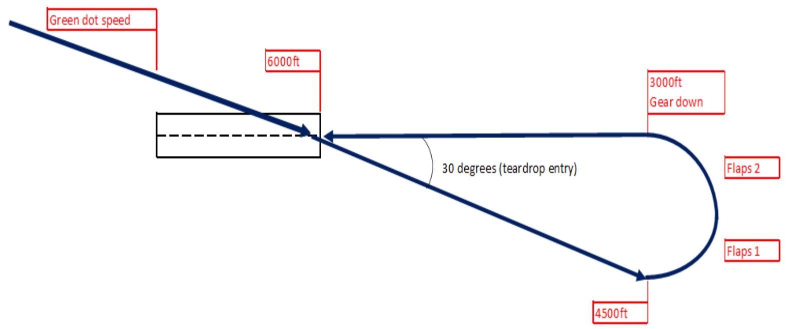


Figure 12. Heuristic circling profile

6 Results

This chapter presents the participants' demographic data and the results of the initial interviews, simulation profiles, and questionnaires, followed by a brief result analysis and synthesis that will constitute the base for the subsequent discussion chapter.

6.1 Crew sample size and characteristics

Twenty-four airline pilots took part in this research project. They formed 12 crews that took part in 12 simulations. Out of these 12 simulations, only eight are counted for the research results and analysis. The first three simulations are not counted. They were needed for testing and fine-tuning the research protocol. Crew number 8 is also not counted in the results as they did not manage to perform SIMULATION 3 due to a combination of simulator technical issues and COVID-19 curfew restrictions in Budapest.

The following demographic details concern a population of 16 pilots who constituted crew number 4, 5, 6, 7, 9, 10, 11, and 12. These crews took part in simulations that counted towards the research. The pilots' rank and experience are tabulated as follows:

Rank	%	Nr of pilots
FO	12,50%	2
SFO	37,50%	6
CPT	43,75%	7
LTC	18,75%	3
CARM	6,25%	1
TRI	6,25%	1
TRE	0,00%	0

Table 4. Pilot classification by rank

Experience type	Average hours
Total flight hours	5969,2
Total airline PIC hours	2975
A320 total flight hours	4170,6
A320 total PIC hours	2066,7

Table 5. Pilot average experience

6.2 Initial interviews

During the initial structured interview, all 18 participants answered that they have been taught and used rules-of-thumb throughout their career as airline pilots. The examples they gave are tabulated as follows:

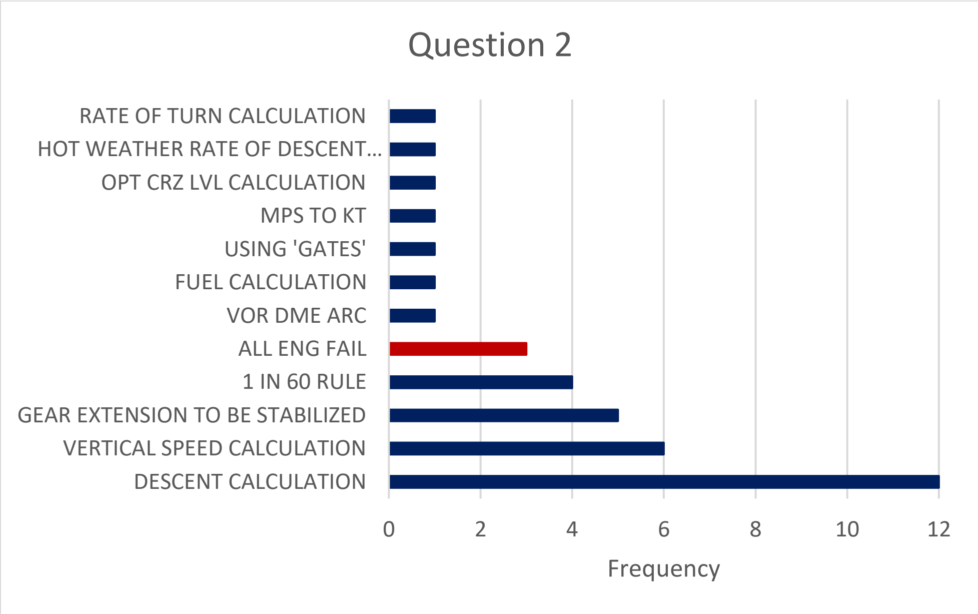


Table 6. Initial interview – participants' responses about previously learned and used heuristics

The participants mentioned the following situations when asked to look at the QRH ABNORMAL AND EMERGENCY PROCEDURES TABLE OF CONTENTS (Airbus, 2019d, ABN) and choose the situations that they perceive as *most critical* in terms of time available, loss of automation, descent profile, and other:

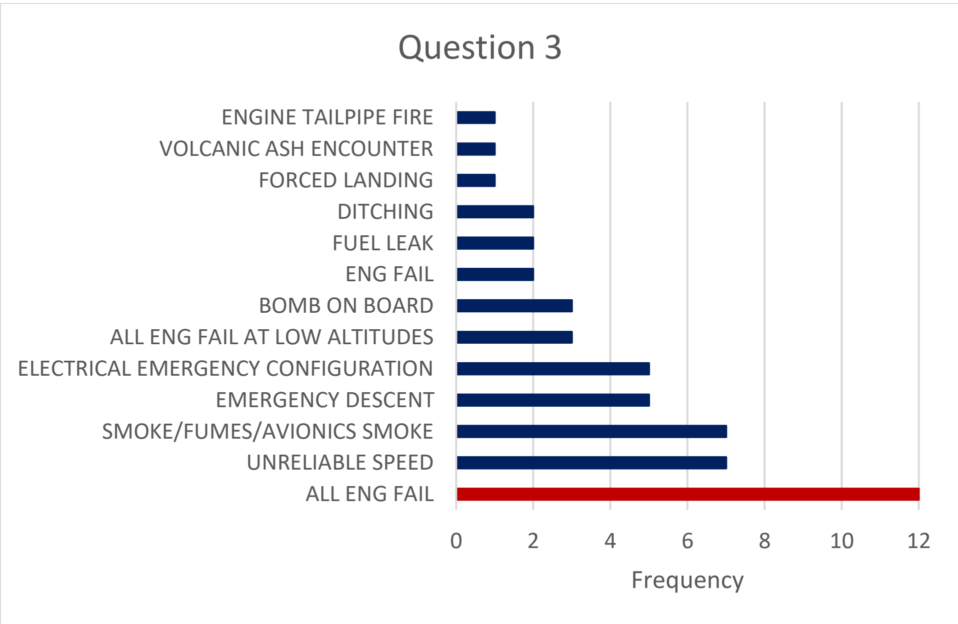


Table 7. Initial interview - participants' opinion about 'the most critical situations' in the Airbus QRH

6.3 Simulations

Google Earth screenshots of all simulated profiles, including detailed tabulated data for the eight comparative simulations and questionnaires, are presented in appendix 5. Details about how the simulation data has been retrieved are presented in appendix 3.

In this subchapter, IAS and DME variation around the reference profiles data summaries and paired samples t-tests (Ross & Willson, 2017) are presented in tabulated form. Visual plots are also presented for an easier understanding of how these parameters varied throughout the descent.

DELTA IAS						
	20000 FT		10000 FT		3000 FT	
	SIM 1	SIM 3	SIM 1	SIM 3	SIM 1	SIM 3
CREW 4	14	70	14	6	0	13
CREW 5	8	6	-6	5	27	32
CREW 6	24	14	34	21	9	18
CREW 7	76	4	24	-2	-6	-3
CREW 9	2	72	38	70	41	-21
CREW 10	115	94	106	87	37	27
CREW 11	12	67	-26	122	24	-7
CREW 12	81	124	9	104	35	-5
t-test: Paired Two Sample for Means						
Mean	41.5	56.375	24.125	51.625	20.875	6.75
Variance	1824	1943.98	1534.98	2479.12	315.839	343.642
Pearson Correlation	0.360626		0.029467		-0.12499	
Hypothesized Mean Difference	0					
df	7					
t Stat	-0.85705		-1.24564		1.46682	
P(T<=t) two-tail	0.419786		0.252971		0.18585	
t Critical two-tail	2.364624					

Table 8. IAS variation around reference profiles and t-test results

Figure 13 shows the variation in IAS (KT) around the Airbus QRH profile at 3000ft, FL100, and FL200, for simulations that used Airbus QRH only.

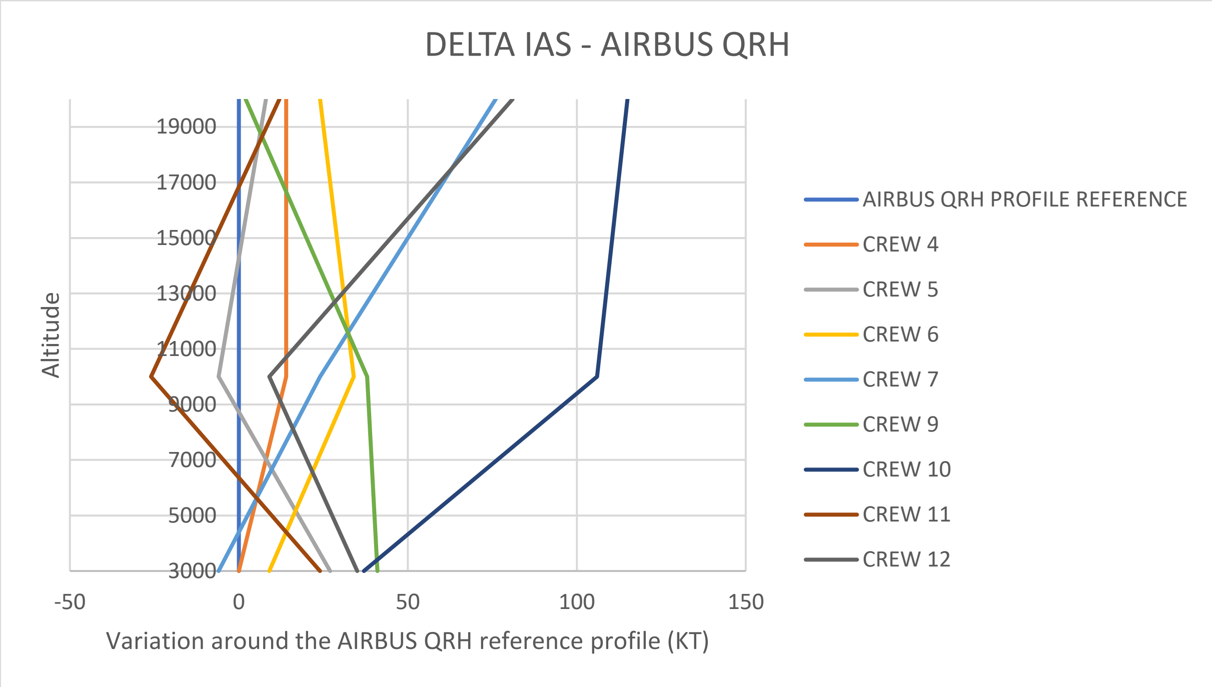


Figure 13. IAS variation around the Airbus QRH profile – simulations using Airbus QRH only

Figure 14 shows the variation in IAS around the heuristic profile at 3000ft, FL100, and FL200, for simulations that used Airbus QRH + Heuristics.

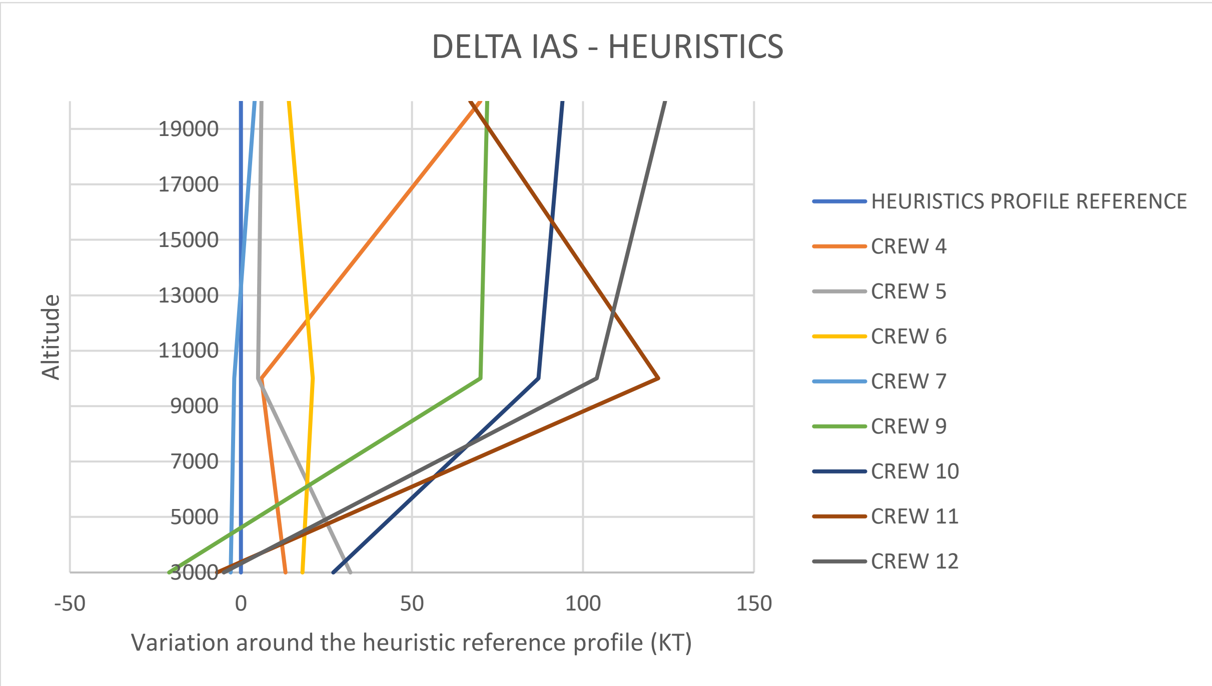


Figure 14. IAS variation around the heuristics profile – simulations using Airbus QRH + Heuristics

DELTA DME						
	20000 FT		10000 FT		3000 FT	
	SIM 1	SIM 3	SIM 1	SIM 3	SIM 1	SIM 3
CREW 4	14.07	19	0.5	3.7	-1.24	-0.55
CREW 5	2.4	16.2	-10.5	-4.4	-1.66	-2.22
CREW 6	1.3	-10.7	-2.25	-1.4	1.2	-0.3
CREW 7	-0.95	2.5	-1.36	-0.2	1.48	-1.03
CREW 9	-0.82	21.53	-5.54	7.04	-0.25	-0.87
CREW 10	-9	2.75	0	4.04	5.9	-0.1
CREW 11	-0.5	-6.92	-12.02	1.5	-1.39	-0.6
CREW 12	8	2.84	-2.74	1.47	-0.18	0.01
t-test: Paired Two Sample for Means						
Mean	1.8125	5.9	-4.23875	1.46875	0.4825	-0.7075
Variance	46.5655	141.822	22.3365	12.5837	6.12830	0.50062
Pearson Correlation	0.330752		0.342696		0.462726	
Hypothesized Mean Difference	0					
df	7					
t Stat	-0.99639		-3.33511		1.50405	
P(T<=t) two-tail	0.35224		0.01250		0.17627	
t Critical two-tail	2.36462					

Table 9. DME variation around reference profiles and t-test results

Figure 15 shows the distance variation (DME) around the QRH profile at 3000ft, FL100, and FL200, for simulations that used Airbus QRH only.

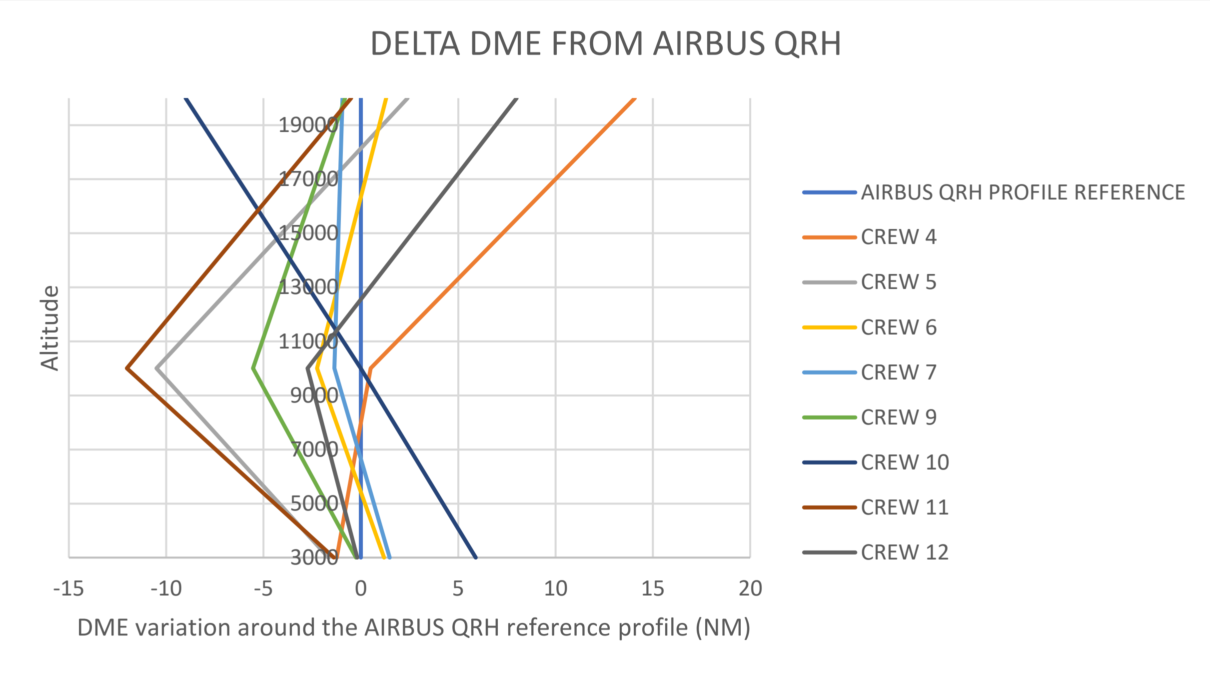


Figure 15. DME variation around the Airbus QRH profile – simulations using Airbus QRH only

Figure 16 shows the distance variation (DME) around the heuristic profile at 3000ft, FL100, and FL200, for simulations that used Airbus QRH + Heuristics.

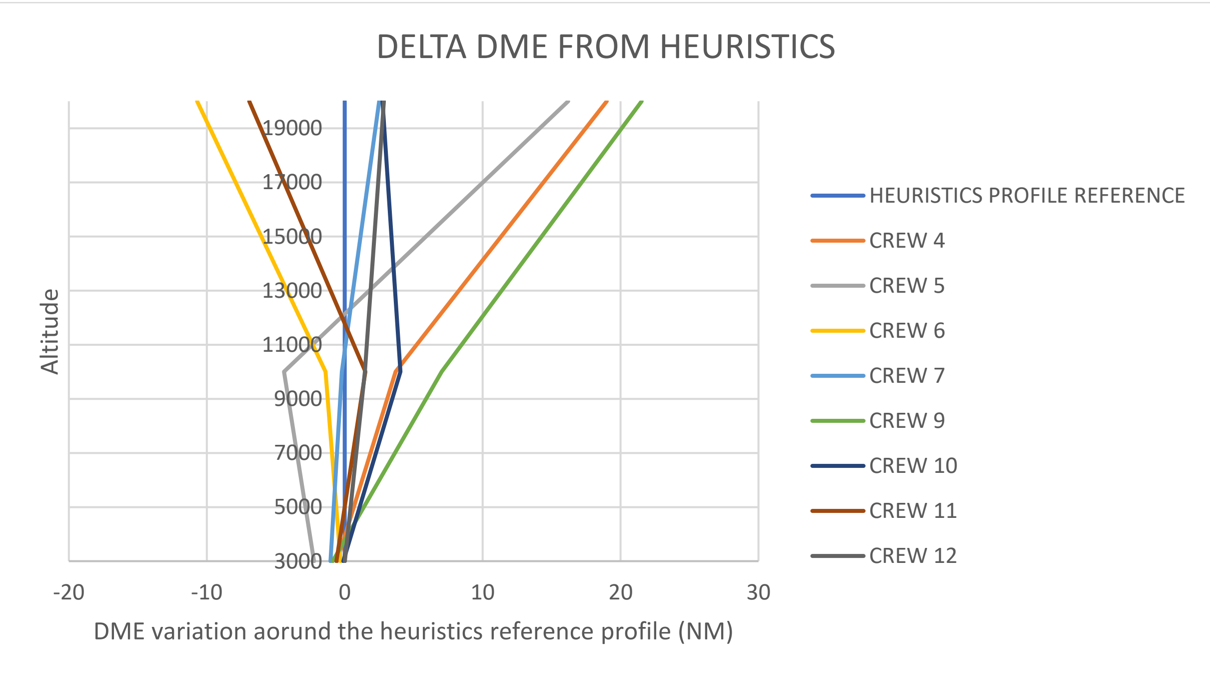


Figure 16. DME variation around the heuristic profile – simulations using Airbus QRH + Heuristics

The simulations that used heuristics indicate that pilots managed to improve the control accuracy during the descent, more notably in the later stages of the descent, when the time and altitude resources are narrowing down to zero at touch down. Figure 16 shows how actual profiles converged towards the heuristic reference profile, indicating that pilots were able to effectively anticipate and accommodate flight path trends (Gawron, 2008), demonstrating a significantly improved ability to adjust the profile, trading off speed to come closer to the distance (DME)/altitude reference. The speed variation around the heuristic profile (Figure 14) indicates that pilots managed to be closer to the heuristic reference profile when approaching the ground.

Tables 8 and 9 indicate decreasing P values of the t-tests in the later stages of the glide for both IAS and DME variations data (Figures 13, 14, 15, and 16). It can be concluded that the difference made by adding judgment heuristics to the Airbus procedure becomes more significant in the later stages of the glide.

Finally, suppose we are to analyse the performance of the JCS (Hollnagel & Woods, 2005) (aeroplane, pilots, procedures, environment, available runways) in terms of reaching or not the desired outcome (landing and stopping on a reachable runway). In that case, the results are as follows:

0=crashed landing, 1=successful landing

	SIM 1	SIM 3
CREW 4	0	1
CREW 5	0	1
CREW 6	0	1
CREW 7	0	1
CREW 9	1	1
CREW 10	0	1
CREW 11	1	1
CREW 12	1	1

t-test: Paired Two Sample for Means

Mean	0.375	1
Variance	0.267857	0
Observations	8	8
Hypothesized Mean Difference	0	
df	7	
t Stat	-3.41565	
P(T<=t) two-tail	0.011201	
t Critical two-tail	2.364624	

Table 10. Simulation outcomes t-test

This t-test indicates that the judgment heuristic addition to the manufacturer procedure made a significant difference in the JCS's desired performance (Hollnagel & Woods, 2005).

6.4 Questionnaires

The pilots had to individually fill out an identical set of questionnaires after their first simulation (using only the Airbus QRH and referred to as the 'Airbus QRH Simulation') and after their third simulation (using the Airbus QRH and the briefed and practised judgment heuristics and referred as the 'Heuristics Simulation'). Each questionnaire contained three rating scales (Gawron, 2008):

- China Lake Situational Awareness Rating Scale
- Bedford Workload Scale
- Modified Cooper-Harper Rating Scale to measure navigational decision-making effort

The results are as follows:

6.4.1 China Lake Situational Awareness Rating Scale

Pilots have rated their perceived situational awareness at FL300, FL200, FL100, 6000ft. The following graphs depict the pilots' SA progression throughout the glide.

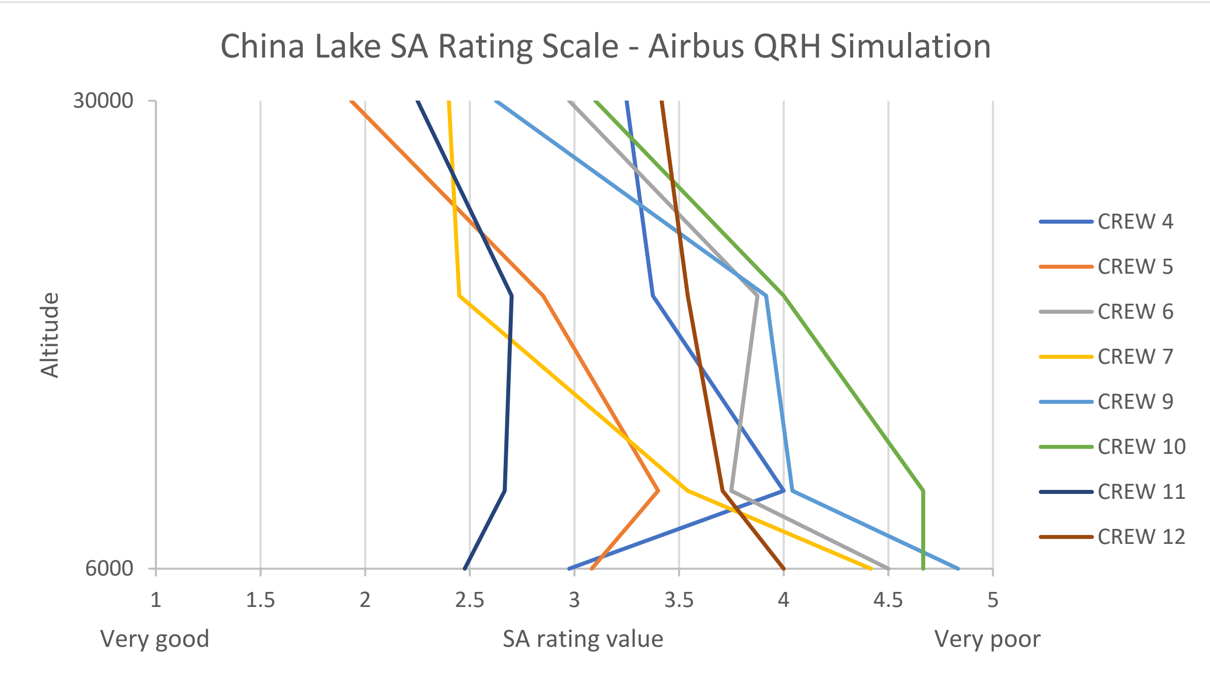


Figure 17. Results: China Lake Situational Awareness Rating Scale - Airbus QRH simulation

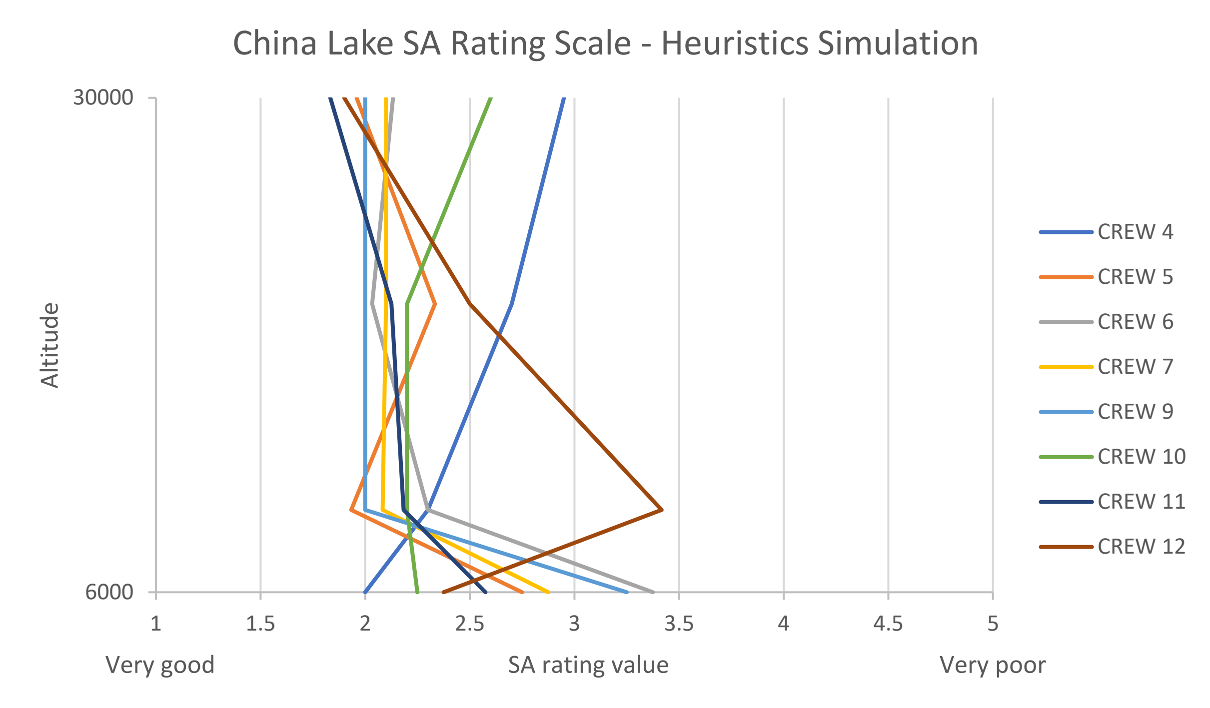


Figure 18. Results: China Lake Situational Awareness Rating Scale - Heuristics Simulation

CHINA LAKE SA RATING SCALE (AVG) RESULTS		
ALT	SIM 1	SIM 3
30000	2.9375	3.625
20000	2.6875	3.625
10000	2.125	3.5625
6000	1.875	3.375

t-test: Paired Two Sample for Means

Mean	2.40625	3.546875
Variance	0.240885	0.013997
Observations	4	4
Pearson Correlation	0.863318	
Hypothesized Mean Difference	0	
df	3	
t Stat	-5.80145	
P(T<=t) two-tail	0.010192	
t Critical two-tail	3.182446	

Table 11. China Lake SA Rating Scale crew average results and t-test results

Comparing the two situational awareness rating scales in Figures 17 and 18, the t-test results in Table 11 indicate that judgment heuristics significantly improved the crews' perceived situational awareness (knowledge of energy state/environment/gliding distance, and ability to anticipate or accommodate trends) (Gawron, 2008).

6.4.2 Bedford Workload Scale

The pilots rated their perceived cognitive effort to manage the workload as follows:

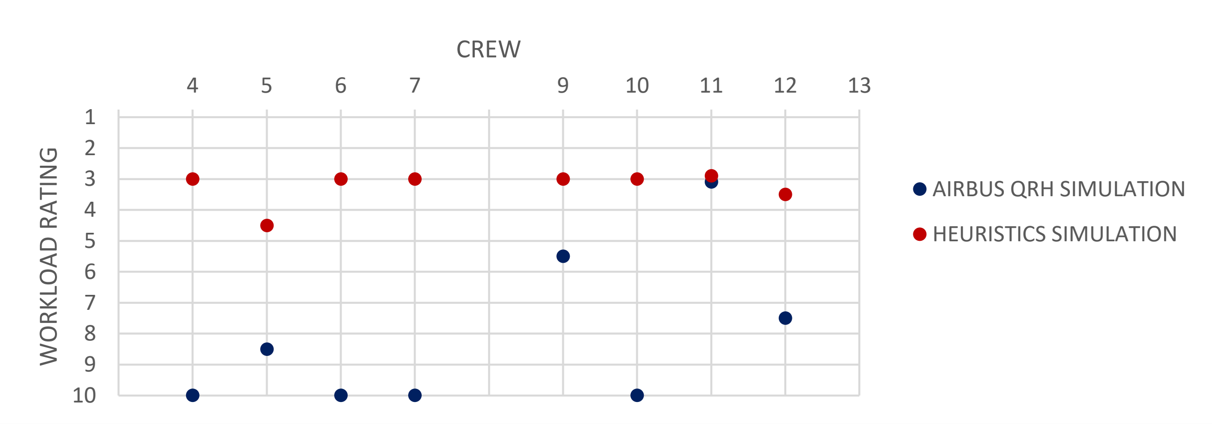


Figure 19. Pilots' rating on the perceived effort to manage the workload

BEDFORD WORKLOAD RATING SCALE		
	SIM 1	SIM 3
CREW 4	10	3
CREW 5	8.5	4.5
CREW 6	10	3
CREW 7	10	3
CREW 9	5.5	3
CREW 10	10	3
CREW 11	3	3
CREW 12	7.5	3.5
t-test: Paired Two Sample for Means		
Mean	8.0625	3.25
Variance	6.816964	0.285714
Observations	8	8
Pearson Correlation	0.038386	
Hypothesized Mean Difference	0	
df	7	
t Stat	5.14642	
P(T<=t) two-tail	0.001329	
t Critical two-tail	2.364624	

Table 12. Bedford Workload Rating Scale crew average results and t-test results

Comparing the workload rating results in Figure 19, the t-test results in Table 12 indicate that judgment heuristics significantly improved the crews' perceived ability to manage their workload.

6.4.3 Modified Cooper-Harper Rating Scale to measure Decision-Making

The pilots rated the decision-making difficulty as follows:

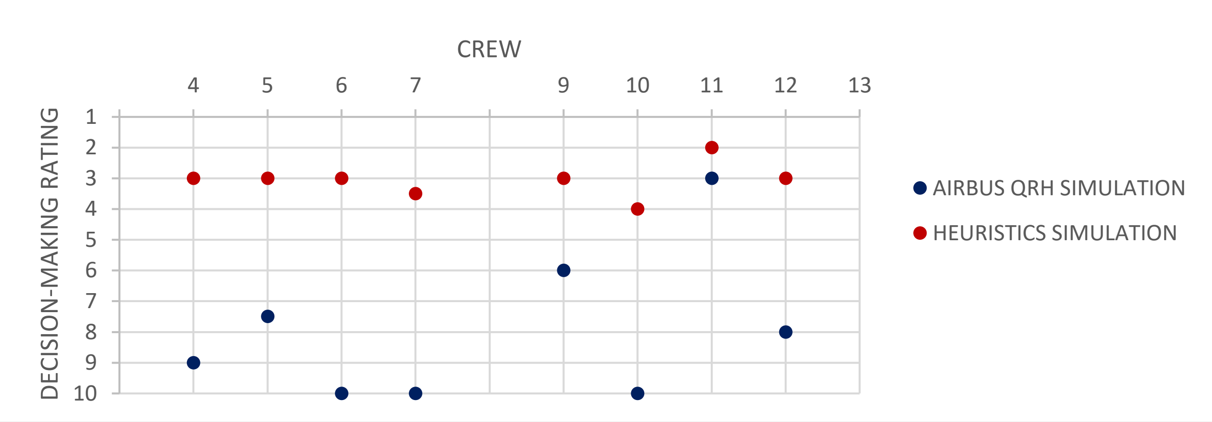


Figure 20. Pilots' rating on the perceived difficulty to make effective navigational decisions

MODIFIED COOPER-HARPER RATING SCALE		
	SIM 1	SIM 3
CREW 4	9	3
CREW 5	7.5	3
CREW 6	10	3
CREW 7	10	3.5
CREW 9	6	3
CREW 10	10	4
CREW 11	3	2
CREW 12	8	3

t-test: Paired Two Sample for Means

Mean	7.9375	3.0625
Variance	6.03125	0.316964
Observations	8	8
Pearson Correlation	0.829805	
Hypothesized Mean Difference	0	
df	7	
t Stat	6.848583	
P(T<=t) two-tail	0.000242	
t Critical two-tail	2.364624	

Table 13. Modified Cooper-Harper Rating Scale crew average results and t-test results

Comparing the decision-making rating results in Figure 20, the t-test results in Table 13 indicate that judgment heuristics significantly improved the crews' perceived ability to make effective navigational decisions.

6.5 Results analysis

The average delta IAS presented in Figure 21 shows that the crews that have used heuristics in addition to the Airbus QRH managed to consistently adjust their altitude/IAS, getting closer to the reference values approaching the landing.

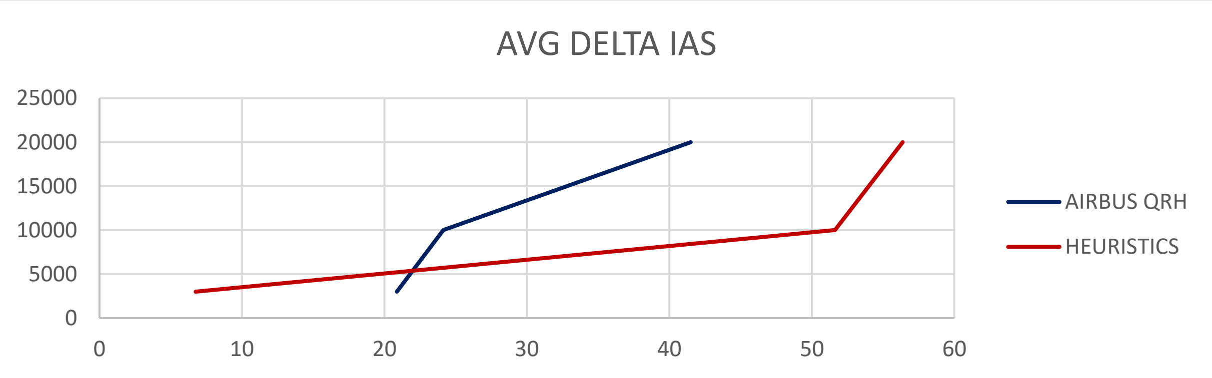


Figure 21. Delta IAS average: Airbus QRH and heuristics simulations comparison

The average delta DME presented in Figure 22 shows that the crews that have used heuristics in addition to the Airbus QRH managed to consistently adjust their altitude/DM, getting closer to the reference values approaching the landing.

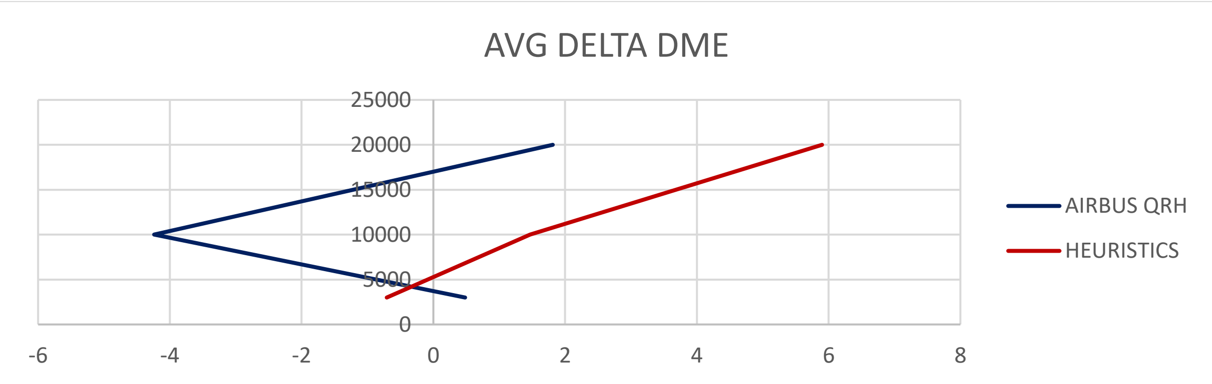


Figure 22. Delta DME average: Airbus QRH and Airbus QRH + Heuristics simulations comparison

Both IAS and DME for given altitudes show different crew ability to anticipate and accommodate trends throughout the general descent profile when using heuristics as an addition to the Airbus QRH.

The China Lake Situational Awareness Rating Scale (Gawron, 2008, p.239) has been used to individually measure the pilots' perceived elements of situational awareness throughout the descent. Three sub-components were measured:

1) knowledge of energy state/environment/gliding distance
2) ability to anticipate or accommodate trends
3) shedding of tasks

The original rating scale is presented in Table 8:

SA Scale Value	Content
VERY GOOD 1	Full knowledge of a/c energy state/tactical environment/mission Full ability to anticipate or accommodate trends
GOOD 2	Full knowledge of a/c energy state/tactical environment/mission Partial ability to anticipate or accommodate trends No task shedding
ADEQUATE 3	Full knowledge of a/c energy state/tactical environment/mission Saturated ability to anticipate or accommodate trends Some shedding of minor tasks
POOR 4	Fair knowledge of a/c energy state/tactical environment/mission Saturated ability to anticipate or accommodate trends Shedding of all minor tasks as well as many not essential to flight safety/mission effectiveness
VERY POOR 5	Minimal knowledge of a/c energy state/tactical environment/mission Oversaturated ability to anticipate or accommodate trends Shedding of all tasks not absolutely essential to flight safety/mission effectiveness

Table 14. China Lake Situational Awareness Rating Scale (Gawron, 2008, p.239)

Figure 23 presents a comparative average of pilots' perceived SA throughout the descent:

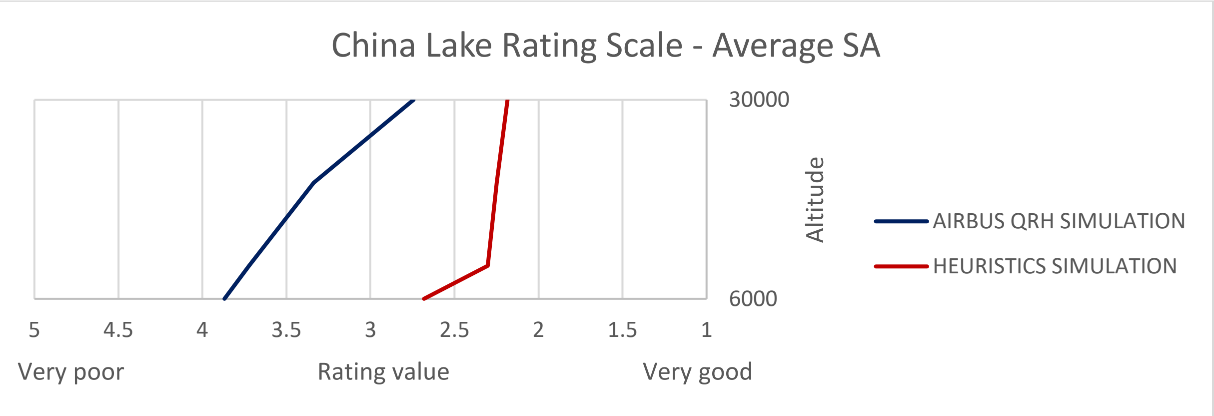


Figure 23. Results: China Lake Situational Awareness Rating Scale – All-crews average

The perceived SA is rated significantly better when using judgment heuristics.

The pilots' perceived effort to manage the workload was measured using the Bedford Workload Scale (Roscoe, 1984, p12-8, as cited by Gawron, 2008, p.161). In case of a crash during the Airbus QRH simulation, some pilots ranked their workload management abilities at 10 (task abandoned/pilot unable to apply sufficient effort).

The original rating scale is reminded below:

1	2	3	4	5	6	7	8	9	10
Workload Insignificant	Workload Low	Enough Spare Capacity For All Desirable Additional Tasks	Insufficient Spare Capacity for Easy Attention to Additional Tasks	Reduced Spare Capacity. Additional Tasks Cannot Be Given the Desired Amount of Attention	Little Spare Capacity: Level of Effort Allows Little Attention to Additional Tasks	Very Little Spare Capacity, But Maintenance of Effort in the Primary Tasks Not In Question	Very high Workload With Almost No Spare Capacity. Difficulty in Maintaining Level of Effort	Extremely High Workload. No Spare Capacity. Serious Doubts as to Ability to Maintain Level of Effort	Task Abandoned. Pilot Unable to Apply Sufficient Effort.

Table 15. Bedford Workload Scale (Roscoe, 1984, p12-8, as cited by Gawron, 2008, p.161)

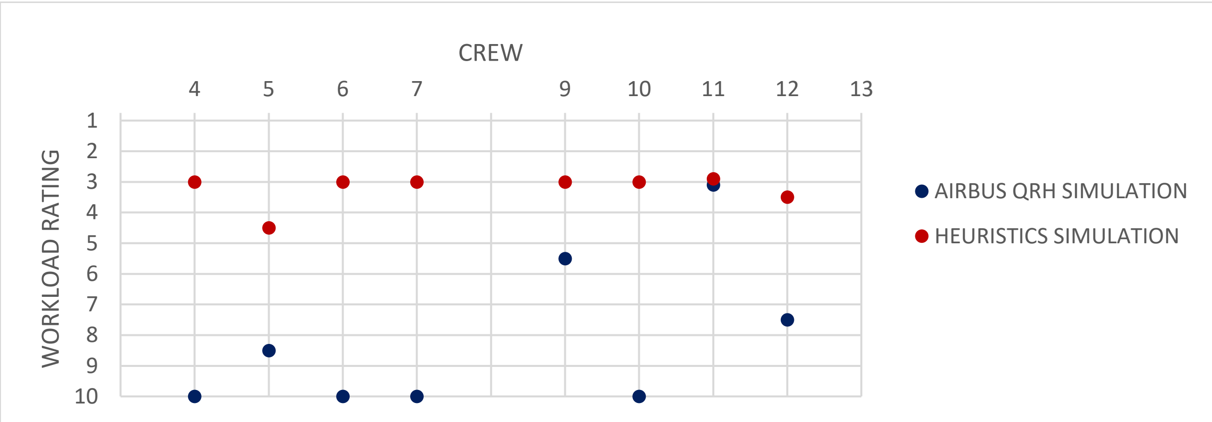


Figure 24. Pilots' rating on the perceived effort to manage the workload

The results indicate a significant improvement in the pilots' perceived ability to manage their workload using judgment heuristics, consistent with the simulation results and the SA ratings.

The pilots' perceived effort to make the required navigational decision to achieve the primary task (land and stop on a runway) was measured using the Modified Cooper-Harper Rating Scale (Gawron, 2008, p.168). In case of a crash during the Airbus QRH simulation, some pilots ranked their effort to make effective navigational decisions at 10 (impossible).

1	2	3	4	5	6	7	8	9	10
Very easy. Highly desirable.	Easy, Desirable	Fair, Mild Difficulty	Minor But Annoying Difficulty	Moderately Objectionable Difficulty	Very Objectionable But Tolerable Difficulty	Major Difficulty	Major Difficulty	Major Difficulty	Impossible

Table 16. Modified Cooper-Harper Rating Scale (Gawron, 2008, p.168)

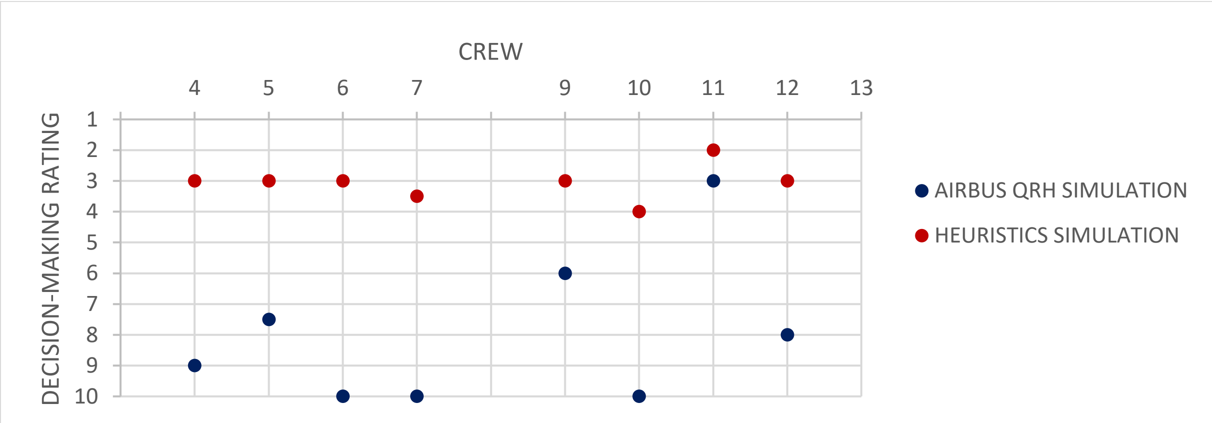


Figure 25. Pilots' rating on the perceived difficulty to make effective navigational decisions

The results indicate a significant improvement in the pilots' perceived ability to make decisions using judgment heuristics, consistent with the simulation results, SA and workload ratings.

6.6 Results synthesis

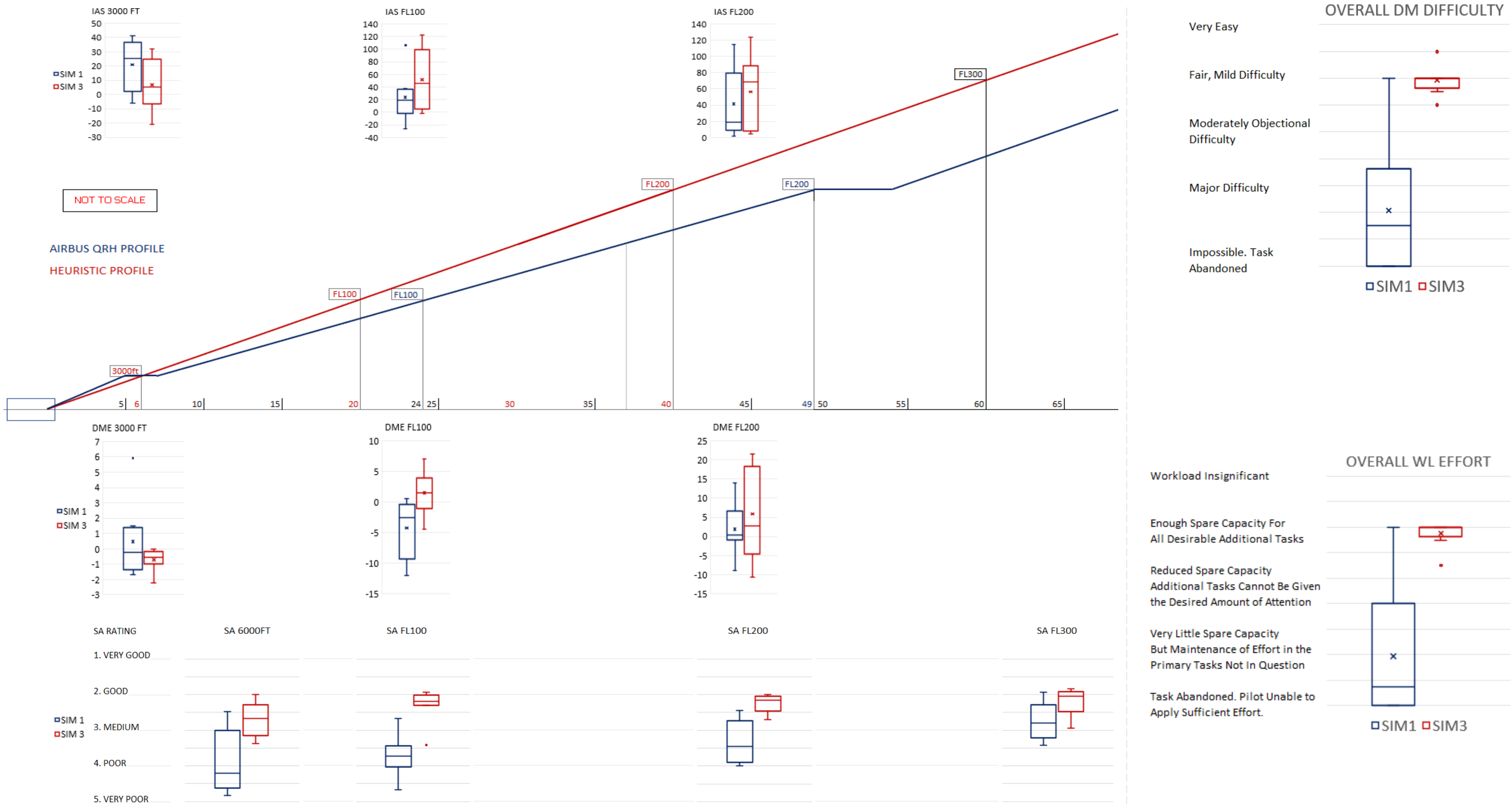


Figure 26. Results synthesis: IAS & DME variations and SA vs. the reference profiles, and OVERALL DM and WL

The variations around the reference profiles and the situational awareness, workload, and decision-making rating scales, consistently indicate that judgment heuristics positively impact the management of the experimented ALL ENGINES FAIL situation at cruising altitudes.

Essential to this research is one sub-component of the China Lake Situational Awareness Rating Scale, namely the "ability to anticipate and accommodate trends" (Gawron, 2008). In Figure 27, this sub-component measurement average may probably indicate the most notable benefit of using judgment heuristics as a feedforward artefact, directly impacting the pilots' perceived ability to use anticipatory control (Hollnagel & Woods, 2005) and directly contributing to all the other results:

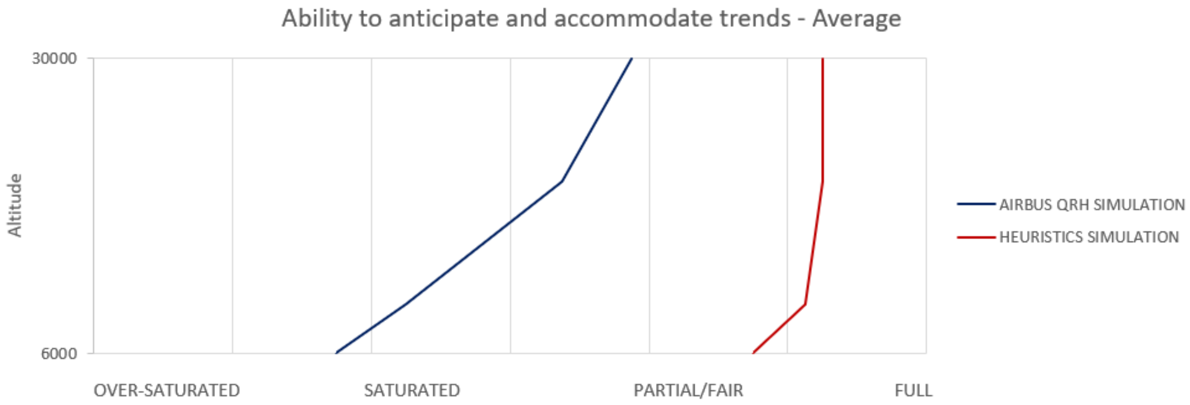


Figure 27. China Lake SA Rating Scale (Gawron, 2008) - ability to anticipate and accommodate trends - all crews average

7 Analyses and Discussion

The previous chapter has presented a summary of the most relevant findings from the simulations and the questionnaires. The findings indicate that the addition of judgement heuristics to the Airbus A320 ALL ENG FAIL QRH procedure (Airbus, 2019d, ABN 19.01A) could positively impact the pilots' management of the situation, with particular reference to SA, DM difficulty, and workload management abilities (Gawron, 2008). These improvements could be detected both based on the pilots' self-assessment and based on the fact that the addition of judgement heuristics has led to an increased number of successful outcomes (landing and stopping on a reachable runway) in the simulations (see Table 10).

This chapter interprets the findings in the theoretical context of Human Factors and Ergonomics (HF/E) (Wilson & Sharples, 2015) and the Cognitive Systems Engineering (CSE) (Hollnagel & Woods, 2005), delineated in the literature review. More specifically, I explore three directions in the subsequent discussion: a) the avenues for further research; b) the comparative performance of JCS with and without the addition of judgement heuristics; and c) the comparative improvements to the pilots' perceived ability to maintain SA, make effective navigational decisions, and manage workload, after the addition of judgement heuristics. The chapter also analyses the Airbus procedure design and its impact on the pilots' ability to make practical navigational trade-offs and concludes by explaining the findings by referencing Hollnagel and Woods' (2005) principle of control modes (p. 148).

7.1 Initial interviews

The participants' answers to the initial structured interview questions indicate that:

Firstly, heuristics are part of the pilots' normal and abnormal operations 'toolbox', as pilots know and use judgment heuristics for various normal and abnormal situations (Table 6).

Secondly, all the interviewed pilots unanimously consider the ALL ENGINE FAIL condition as most critical, followed by the UNRELIABLE SPEED and SMOKE/FUMES/AVIONICS SMOKE (Table 7). The ALL ENGINE FAIL situation is perceived as most critical in terms of descent profile management (see 6.2. above). The UNRELIABLE SPEED can lead to a most severe loss of automation, and the SMOKE/FUMES/ AVIONICS SMOKE is perceived as most critical in terms of time available.

The initial interviews (Appendix 6) indicate that pilots are familiar with and prefer using simplified heuristics in normal and abnormal situations. In the latter case, they are concerned and possibly uncomfortable, and therefore more stressed about managing most critical situations in terms of descent profile, loss of automation, and time available. Such results may indicate valuable further research directions to explore the potential benefits of training heuristics for other types of abnormal situations (see also 7.9. below).

Notably, during the initial interview, crews 9, 11, and 12 stated they knew some judgement heuristics for the ALL ENGINES FAIL situation. These are also the crews that managed to land and stop on a runway during SIMULATION 1. This previous heuristic knowledge may explain their SIMULATOR 1 performance and the subsequent higher workload and decision-making questionnaire ratings. The crew 11 captain stated that he was specifically trained and had airline training: “if at 6NM you are above 3000ft lower the gear earlier, and if below, lower the gear later”. This crew indicated the highest values on the workload and decision-making ratings. Nevertheless, using the more elaborated judgment heuristics studied in this research, crew 11 also showed improvement in their SA and decision-making ratings between simulations 1 and 3.

7.2 Simulations

The results suggest that using judgment heuristics in the simulated scenario could be beneficial: nine out of the twelve crews participating in this research crashed on the first simulation when using only the Airbus QRH procedure. These numbers include the first three simulation test crews and crew number eight, who did not have time to complete the third simulation due to delay caused by simulator technical issues and curfew restrictions in Budapest. Of these twelve crews, given the incomplete simulation of crew number eight, eleven crews managed to land and stop on an available runway using the judgment heuristics during SIMULATION 3.

Focusing only on the eight simulations that were completed in a standardized manner, starting with crew number 4 (following protocol testing and adjustment), five out of eight crashed on the first attempt using only the Airbus QRH. By contrast, all eight crews managed to land after being taught and trained on ALL ENG FAIL judgement heuristics, i.e., after having added such heuristics to their cognitive ‘toolbox’. The ‘rules-of-thumb’ presented to the pilots primarily involve simple altitude/distance calculations, potentially allowing them to make corrections in the speed/altitude trade-offs. Therefore, to determine the effect of applying the heuristics, Figure 28 compares simulations 1 and 3 in the IAS and DME variations around their reference profiles.

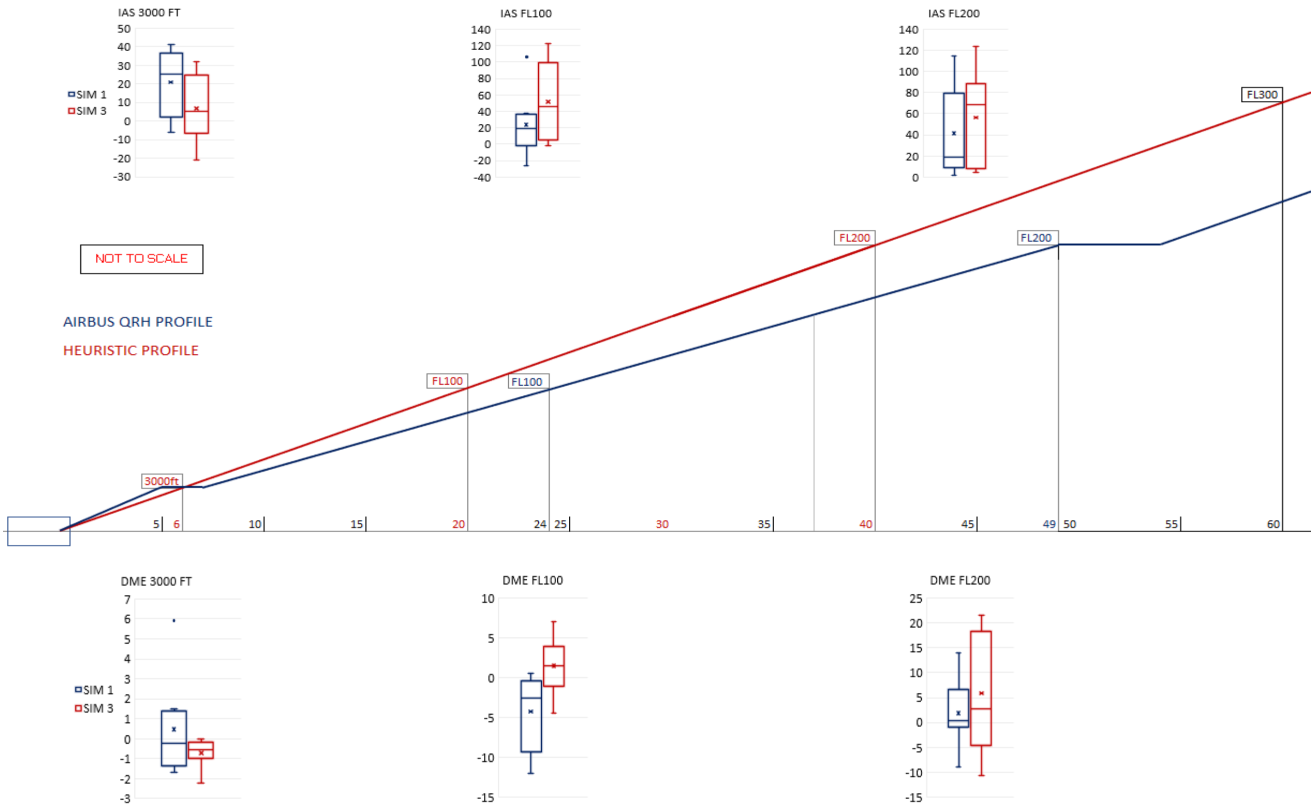


Figure 28. IAS and DME variations around the reference profiles (detail of Figure 26)

The IAS and DME variations around the Airbus QRH profile do not show any clear pattern or correlation, which may be the result of a "trial-and-error type of performance" where "the choice of next action is basically *random* [emphasis added]" (Hollnagel & Woods, 2005, p.146), indicators of a *scrambled control mode* (p.148).

By contrast, the IAS and DME variations around the heuristic profile can be correlated and indicate that the pilots effectively prioritized and managed the distance/altitude ratio, reaching the desired outcome (land and stop on an available runway). The IAS variations are considerable at all levels, meaning that the pilots effectively traded-off speed to reach a certain altitude at a certain distance, as required by the heuristic profile. The DME variations consistently reduced approaching the runway. An increased pilots' ability to control the glide, where the action selection was based on a clear plan, displays the signs of a *tactical control mode* (Hollnagel & Woods, 2005, p.148).

The above comparison suggests that the heuristics offered pilots the possibility to control the flight path effectively, making the necessary corrections to follow the desired profile.

7.3 Questionnaires

The questionnaire results show increases in the pilots' perceived situational awareness, ability to make navigational decisions, and ability to manage the workload after the inclusion of judgement heuristics in their cognitive 'toolbox'. As discussed in section 6.6. (Figure 27), the "ability to anticipate and accommodate trends" (Gawron, 2008) may be the main contributor to all the other comparative results showing such differences. More specifically, Figure 29 indicates the SA ratings following SIMULATION 3 consistently having higher values and less variation at all measurement points than the values following SIMULATION 1. All other things being equal (simulation variables), this difference may be due to the effectiveness of judgment heuristics as a reliable and straightforward feedforward artefact. The overall decision-making (Figure 24) and workload rating scales (Figure 25) results confirm the benefits.

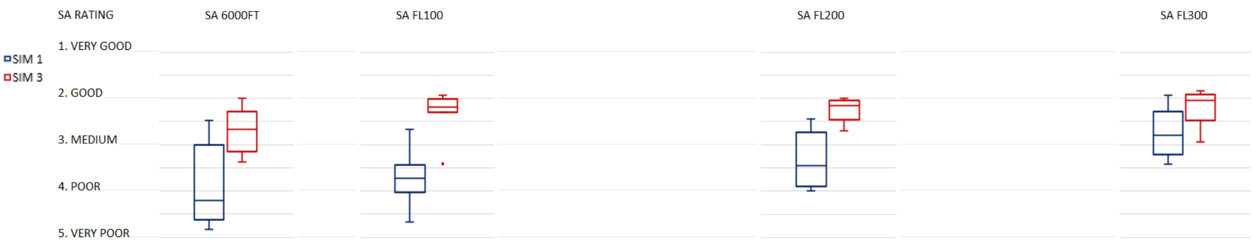


Figure 29. SA variations (detail of Figure 26)

What makes judgment heuristics a more effective navigational tool than the manufacturer procedure? Possible answers are discussed in the following three sections. I will be looking at the manufacturer procedure design and compare it with the judgment heuristics through the lenses of typicality and familiarity (Clewley & Nixon, 2020), HF/E (Wilson & Sharples, 2015) perspective, the 'right-right-right' rule, and the concept of 'simplicity-complexity trade-off'. Finally, the principle of control modes will integrate everything into a CSE (Hollnagel & Woods, 2005) approach.

7.4 A HF/E approach to the Airbus ALL ENGINES FAIL procedure and heuristic profile

During the simulations, all participating pilots knew what to expect. The effects of startle and surprise have thus been minimised. Despite this, it is tacit knowledge in the field that even experienced pilots may struggle to make simple times two multiplications while manually flying a degraded aeroplane. The cognitive impairment resulting from this abnormal situation was most evident throughout SIMULATION 1 (without heuristics) across most pilots, which is reflected in the situational awareness, workload, and decision-making questionnaire results (Gawron, 2008).

The Airbus A320 ALL ENG FAIL QRH procedure does not sufficiently account for the pilots' foreseeable contextual cognitive abilities, needs, and limitations (Wilson & Sharples, 2015). When pilots suffer from decreased cognitive abilities as a result of an abnormal situation (such as ALL ENG FAIL), they may not be able to effectively manage complex checklists while naturally prioritizing the higher-level priorities – fly and navigate – as demanded by the Airbus Golden Rules. The pilots need simplified alternatives to meet these essential higher-level priorities. The Airbus procedure fails to meet these necessities because it uses complicated, unfamiliar, and atypical profiles that its users cannot effectively operationalize (Clewley & Nixon, 2020a).

Are there any examples of procedures that better meet these pilots' needs in an ALL ENGINES FAIL situation? Two such instances are provided in the CRJ 900 QRH and BAE AVRO 146RJ FCOM procedures.

CRJ 900 QRH (Bombardier, 2019, EMER 1-4)

In the late stages of this procedure, clear navigation guidance is offered: 5000ft over the airfield, turn with 20-30 degrees bank into the downwind maintaining the airspeed, at 2500ft abeam the landing area, start turning final to be established at 1500ft and when runway assured, lower the gear and configure with flaps 20, flying a given reference speed (Bombardier, 2019, EMER 1-10).

Moreover, this type of flying over the field approach to land is practised during the early stages of the flight school when pilots must demonstrate that they can land with a simulated engine failure, highlighting how Bombardier builds their procedure on familiar pilot knowledge and experience (Clewley & Nixon, 2020b).

AVRO 146RJ Abnormal and Emergency Checklists (British Aerospace, 2007, 6.18):

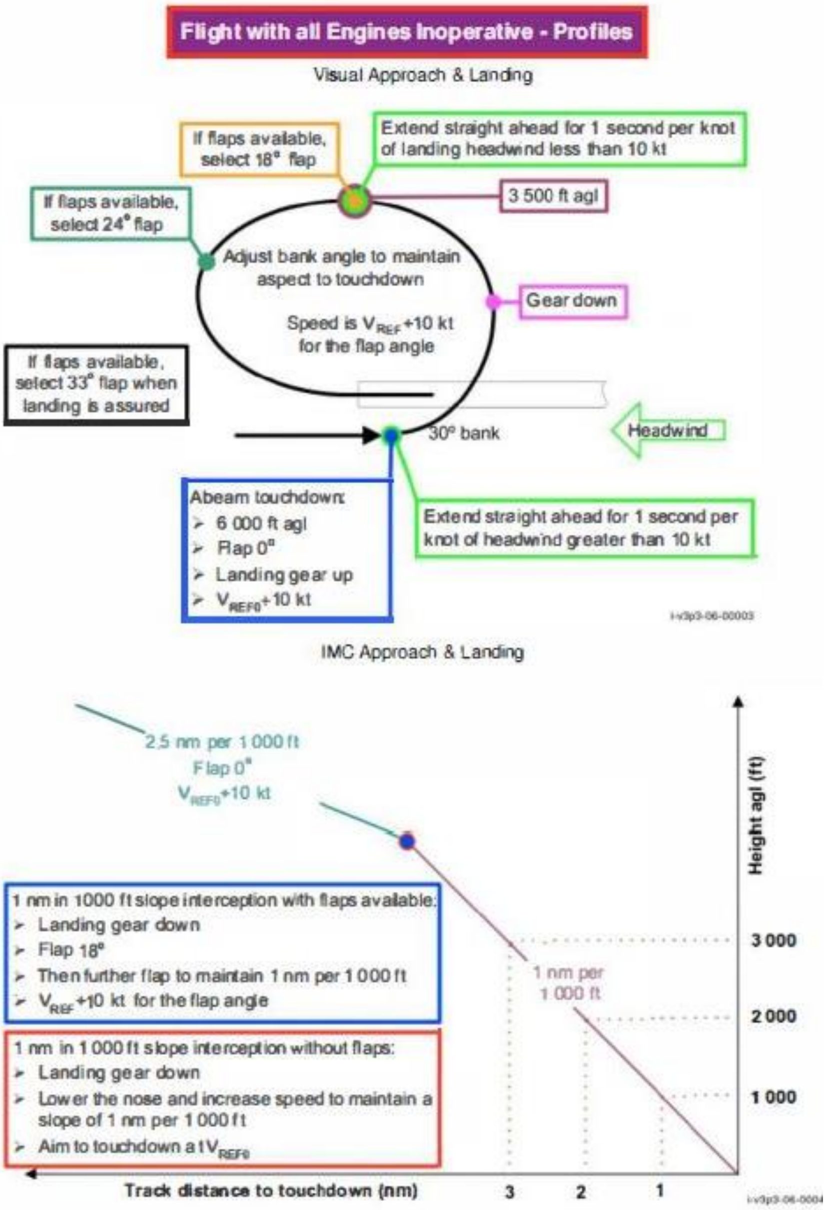


Figure 30 AVRO 146RJ FCOM (British Aerospace, 2007, 6.18)

Alternatively, BAE offers a clear and simplified three-page checklist, with one-page navigation information in graphical form (British Aerospace, 2007, 6.17). This graphic pattern considers the previous knowledge and experience any pilot has from flight school. It offers clear guidance on how and when to configure the aircraft, considering wind adjustments using typical and familiar principles that airline pilots use during usual traffic patterns (Clewley & Nixon, 2020b).

Both examples demonstrate that procedures can indeed be devised with sufficient detail and in a manner that accounts for the pilots' foreseeable cognitive limitations in abnormal situations, highlighting the above-mentioned gap in the Airbus QRH procedure.

This conclusion also has theoretical support. In the context of discussing conceptual categories, Clewley & Nixon (2020) suggest that pilots' variation in event knowledge can be explained through the lenses of *typicality* and *familiarity*. They argue that "typical instances are more readily learned and more easily recognized—they are stronger concepts and describe where our knowledge is concentrated" (Rosch et al., 1976; Sandberg et al., 2012; Storms et al., 2000, as cited by Clewley & Nixon, 2020). The authors also quote that "familiarity covaries with repetition, so familiarity is an important driver of recognition, retrieval, and learning" (Barsalou, 1985; Nosofsky, 1988; Rosch, 1978, as cited by Clewley & Nixon, 2020). The upshot of the argument is that pilot training can be improved by familiarizing the crew with typical and non-typical event structures.

With this in mind, one potential avenue for further research could investigate whether the A320 ALL ENG FAIL QRH procedure can be designed more effectively if connected with typical and familiar cognitive elements, such as the AVRO 146RJ QRH visual profile example. If designed using typical and familiar elements (and practised), complex procedures may significantly help pilots to better manage difficult situations when their mental capacity may be diminished.

7.5 A CSE perspective comparison: A320 QRH procedure and judgment heuristics

In a Joint Cognitive Systems approach (Hollnagel & Woods, 2005), the A320 ALL ENGINES FAIL QRH procedure and the judgment heuristics act as artefacts that pilots can use to calculate and control navigational profiles. These artefacts are structured differently, and they also functionally impact the JCS. The next sections analyse these differences using the 'right-right-right' rule and the concept of Simplicity-Complexity Trade-Off (Hollnagel & Woods, 2005).

7.5.1 The 'right-right-right' rule

Hollnagel & Woods (2005) argue that the 'right-right-right' rule presents a design principle that is "simplicity itself and would undoubtedly have a significant effect on practice if it were only possible to realise it" (p.83). This idealized interface design model suggests presenting the right information, in the right form, at the right time.

The right information

A way of defining 'right information' is "to consider specific situations as they are defined by the system design. An almost trivial example of that is a situation described by operating procedures – both for normal operations and emergencies." (Hollnagel & Woods, 2005, p.84)

By all metrics in this research, the simulations suggest that judgment heuristics may be a more effective tool in enhancing the crew's capability to control the gliding profile (Figure 28 and Section 7.2. on Simulations above). Does this suggest that the information presented by the manufacturer is not right or that heuristics information is 'more' right? Certainly, the information based on the manufacturer's data is technically more accurate than the simplification offered by judgment heuristics - the QRH navigational information is technically correct, hence, technically right. Nevertheless, both the analysis of this procedure in Chapter 5 above and the different aggregate outcomes in Simulations 1 and 3 indicate that this navigational information does not effectively help pilots manage their abnormal ALL ENG FAIL situation. This is likely to do not with information accuracy but with it being presented in an atypical and unfamiliar form that the pilots cannot effectively process (Clewley & Nixon, 2020a).

In the right form

The Airbus QRH probably tries to address the real complexity as much as possible and to offer the necessary steps to manage it. The judgment heuristics simplify the situation and therefore reduce the perceived complexity. "If the system can be made to look simpler, then it will also be simpler to control." (Hollnagel & Woods, 2005, p.85) The present research demonstrates that such simpler tools (despite being less accurate) function better in the simulated experiment.

At the right time

Feedforward control is more powerful than feedback control, as pointed out by Conant & Ashby (1970, p. 92, as cited by Hollnagel & Woods, 2005).

The ECAM estimated gliding range is a piece of feedforward information that may help pilots make an initial assessment and decide their landing area. The QRH presents various configuration descent profiles that could hypothetically help pilots monitor and adjust their gliding profile. However, given the sequence in which it is presented, hence the timing in the management flow, it can be used mostly reactively to make corrections based on feedback (already too high/too low), which situation "is likely to fail when time becomes too short, simply because feedback cannot be processed fast enough to be of use."(Hollnagel & Woods, 2005)

Alternatively, the judgment heuristics can act as a feedforward and feedback single artefact that is always available at the right time (from the beginning of the event, all the time throughout the descent). It can be used proactively to make an initial assessment of a rough estimate gliding distance available which is required to make a crucial navigation decision in accordance with the Airbus Golden Rules and can be used reactively as a reference to make corrections based on feedback (too high/too low), adjusting the speed and configuration to trade-off altitude and match the required range.

7.5.2 Simplicity-Complexity Trade-Off

The Airbus calculations estimate a potentially longer gliding range, therefore possibly offering more landing airport choices. Using simplified heuristics presents a risk of providing "a conceptually simpler world at the cost of a reduced match to reality" (Hollnagel & Woods, 2005, p.87), which in some hypothetical cases may make a difference on the desired outcome.

The judgment heuristics may enable pilots with reduced cognitive capacity "to structure the information at a higher-level representation of the states of the system; to make a choice of intention at that level; and then to plan the sequence of detailed acts which will suit the higher-level intention" (Rasmussen & Lind, 1981, p.9, as cited by Hollnagel & Woods, 2005).

The QRH can be seen as an artefact developed on a manufacturer procedural prototype model which "assumes that a pre-defined sequence of (elementary) actions or a procedural pattern exists, which represents a more natural way of doing things than others" (Hollnagel & Woods, 2005, p.144). The judgment heuristics are shortcutting mechanisms (Jarvis et al., 2014) that help pilots cope with the failure management in the actual context (prioritizing actions and making navigational trade-offs from the onset of the failure down to landing); therefore, they can be seen as based on a contextual control model which “implies that actions are determined by the context rather than by an inherent sequential relation between them.” (Hollnagel & Woods, 2005, p.144)

The research results indicate that pilots need and prefer simplified tools commensurate with their cognitive abilities and limitations (Wilson & Sharples, 2015) in their contextual time-pressured situation. Such simplified tools help them prioritize essential high-level goals, such as flying (understanding the new actual state) and navigating (anticipating and accommodating trends), and perform complex checklists. The choice of using judgment heuristics for calculating the navigational profile is a clear example of procedural simplicity-complexity trade-off (Hollnagel & Woods, 2005, p.82), which is a form of Efficiency-Thoroughness Trade-Off (ETTO) (Hollnagel, 2009). The pilots prove to be more effective in managing the situation using a simplified and less accurate judgment heuristic instead of being more thorough using the more precise Airbus check-list calculations.

7.6 Discussion summary

This research has aimed to evaluate how the Airbus QRH procedure contributes to the pilots’ management of navigation in an ALL ENGINES FAIL situation at cruising altitude aboard an Airbus A320 and whether the addition of judgment heuristics can improve task performance and the desired outcome. By applying the theoretical frameworks of Human Factors and Ergonomics, and Joint Cognitive Systems, I have argued that the QRH procedure suffers from several deficiencies, all of which are likely to impact the pilots’ ultimate success in implementing it. More specifically, the procedure is couched in atypical and unfamiliar terms, it is not drafted with an eye to the cognitive impairments that are bound to affect pilots in ALL ENG FAIL situations, it does not provide the information ‘in the right form’ or at the ‘right’ or optimal time, and it does not help pilots make Efficiency-Thoroughness Trade-Offs (Hollnagel, 2009) that are needed for the abnormal ALL ENG FAIL context.

The results of SIMULATION 1 provide support for these conclusions, with pilots self-reporting relatively low levels of situational awareness and decision-making abilities and the desired outcome (successful landing) being achieved only in a minority of cases. By contrast, the knowledge and application of judgement heuristics (Simulation 3) appear to be correlated with improvements in virtually all the relevant metrics monitored in this research.

In the experimental scenario, following the onset of the event and under the perceived time pressure, building an initial mental model required to fly and navigate constitutes an essential priority for the pilots, as dictated by the Airbus Golden Rules. According to the manufacturer’s procedural prototype model (Hollnagel & Woods, 2005), the intended navigational state (gliding profile) can be calculated using the information provided by the manufacturer QRH (the object of this research). Considering the QRH procedure design (the format and timing of the navigational information elements), the cognitive effort required to process the QRH navigational information may be incommensurate with the pilots’ available cognitive capacity (Jarvis et al., 2014). This may trigger mainly feedback-based trial-and-error performance, indicating a *scrambled control mode* in SIMULATION 1 (Hollnagel & Woods, 2005).

The application of judgement heuristics in SIMULATION 3 appears to have enabled pilots to effectively control the situation within their foreseeable contextual cognitive abilities and limitations (Amalberti, 2001; Jarvis et al., 2014; Landman et al., 2017a; Leach, 2004; Moriarty, 2015; Rankin et al., 2016, 2013; Wilson & Sharples, 2015), compensating for the Airbus ALL ENG FAIL QRH procedure shortcomings. The heuristics allowed pilots to create "a good representation of the process to be controlled" (Hollnagel & Woods, 2005, p. 138). Based on this navigational process representation, the addition of judgment heuristics as a simplified feedforward artefact to the QRH information allowed the pilots to use anticipatory feedback (Hollnagel & Woods, 2005, p. 138), minimizing the time required to re-evaluate the situation, which directly impacted a series of cognitive processes: cognitive workload (Jarvis, 2010, as cited by Jarvis et al., 2014, p.55), the situational awareness constructs (including the pilots' abilities to anticipate trends) (Gawron, 2008; Neisser, 1976), and the quicker decision-making processes that dictated the actions taken to accommodate the trends (Hollnagel & Woods, 2005; Jarvis et al., 2014).

Improvements to these processes are all recorded in the questionnaires (see Chapter 6). In addition, the application of judgement heuristics ultimately led to more successful simulated landings. The IAS and DME correlations indicated by the simulations show that the pilots demonstrated the ability to make detailed enough navigational calculations (Section 7.2. above). They made continuous speed/altitude trade-offs and proactively compensated between the (predictable) actual and intended states (based on a planned profile), ultimately managing to effectively control the glide and reach the desired outcome, landing and stopping on a runway.

7.7 Research limitations

This research suggests that training in judgment heuristics and simplified workflows may significantly help pilots manage the ALL ENGINE FAIL at cruising altitudes critical situation. However, I have been trained, and I have trained pilots to use heuristics in normal daily operations and various abnormal/emergency scenarios. Therefore, there is a risk of bias in assessing the impact of the heuristics.

As I flew with and trained most of the Cluj-Napoca based pilots who voluntarily participated in this research, I felt the need to limit my direct involvement in the actual simulation and the data acquisition process. Most of the simulations have been done in Cluj-Napoca and were conducted by another simulator instructor. All the questionnaires have been prepared using an online platform and have been independently completed by the pilots using their mobile phones.

I have used a certified fixed base Flight Training Device (FTD) for two simulations and a non-certified simulator for the other six simulations. The accuracy of the simulations is therefore limited. I have tested and compared the studied profiles (ALL ENGINES FAIL judgment heuristics-based straight-in and circling approaches) in the non-certified simulator and a professional certified full-motion A320 simulator in Sofia. The simulated profiles and the aeroplane behaviours were similar.

The accuracy of the retrieved simulation profiles data is limited because all profiles have been manually inserted into Google Earth online platform. The simulators used for this research had limited data output capabilities and required manual reconstruction afterwards.

The sample of pilots used in this research is small. While it is unlikely that the general indication that heuristics positively contribute to the management of the simulation situation would be affected by a bigger sample size, more accurate results could be obtained using more crews.

The methodology used, the One Group Pretest-Posttest experimental design (Campbell & Stanley, 1963, p.7), is not using a control group and is therefore subject to several questions regarding the accuracy and validity of the results, and the potential effect of skilled learning, when pilots improve their performance due to the repetition of the same scenario.

Thus, the results obtained in this research show that the judgement heuristics demonstrate a positive influence where applied and used on the management of the experimental condition (ALL ENGINES FAIL). However, these results cannot exclude any skilled learning effect that may accrue from participants' exposure to the scenario, learning that is gained from the repetition in the experimental design. Further research to explore this effect and its influence on the performance of the crews' performance should be undertaken to confirm the validity of the experiment's conclusion that judgement heuristics improve a crew's performance.

7.8 Further research

As indicated during the initial interview, the three situations perceived by the pilots as most critical (ALL ENG FAIL, UNRELIABLE SPEED, and SMOKE/FUMES/AVIONICS SMOKE) may define the most critical boundaries of an abnormal and emergency situations envelope. It may be that any other abnormal situation may face pilots with a combination of elements specific to at least one of the three boundary situations.

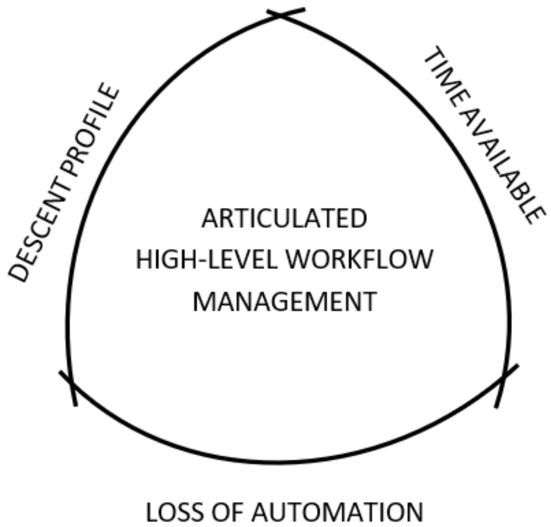


Figure 31. A possible 'most critical situations' boundaries training model

For example, a volcanic ash encounter may block the pitot tubes and flame out the engines. This situation could be plotted at the intersection of the descent profile and loss of automation boundaries (Figure 31) as the pilots would face the combined challenges of ALL ENG FAIL and UNRELIABLE SPEED situations. A cargo smoke situation is a time-critical situation that would challenge the pilots with the most expeditious descent profile and could be plotted at the intersection of the time available and descent profile boundaries. Pilots would face the challenge to make a rapid descent under critical time pressure. A dual hydraulic failure or an emergency electrical configuration situation significantly degrade the aeroplane and may present some fuel available or fuel penalties time pressure (but to a lesser extent than a fire/smoke situation).

In a real-life abnormal or emergency situation, we know that pilots may suffer from the effects of startle and surprise, as confirmed by a vast body of research (Amalberti, 2001; DeLisi, 2018; EASA, 2018; FAA, 1996; Grant & Booth, 2009; Landman et al., 2017a; Landman, Groen, van Paassen, Bronkhorst, & Mulder, 2017b; Leach, 2004; Moriarty, 2015; Rankin et al., 2013, 2015).

Landman et al. (2017) present a conceptual model of startle and surprise, which is based on the perceptual cycle model (Neisser, 1976), the data frame theory of sensemaking (Klein, Phillips, Rall, & Peluso, 2007, as cited by Landman et al., 2017), and literature on startle and stress (Landman et al., 2017a). The authors conclude that the "intervention methods should be focused on instilling a supply of sufficiently elaborate frames" (Landman et al., 2017a). I argue that 'sufficiently elaborate frames' need to be further articulated to make practical sense in the operators' language.

Talone & Jentsch (2015) add another important element to the onset of an abnormal or emergency situation context, namely *distraction*, "the diversion of attention away from activities that are required for the accomplishment of a primary goal to other competing sensory (e.g., visual, auditory, biomechanical) and cognitive activities." (Talone & Jentsch, 2015) They argue that the startle may be less problematic to the flight deck. Still, it can trigger a negative performance, most likely due to the added effects of surprise and distraction.

Rankin, Woltjer, Field, & Woods (2013) conclude that interviews with pilots "suggest that training today does not adequately prepare pilots to cope with surprise" (Rankin et al., 2013), but they offer no practical solution yet. (Rankin et al., 2013)

A possible solution may come from senior British examiner, captain Michael Watt, suggesting to train pilots in a high-level "surprise management workflow", which comprises a well-articulated version of the Airbus Golden Rules and "disciplines the thinking about the right thing". Watt argues that "the challenge is not training the workflow itself, but training pilots who are suffering all the physiological reactions to the surprise, to turn to the workflow." He summarised this situation as a conundrum: "pilots need the cognitive ability to use the workflow exactly when they might not have the cognitive ability to do so", due to the effects of startle and surprise (M. Watt, personal communication, 22 April 2020).

J. Leach, in the 2004 paper Why People 'Freeze' in an Emergency: Temporal and Cognitive Constraints on Survival Responses, argues: "The brain is structured in such a way that response time can be improved through practice, training, and experience in advance of any disaster. Such preparation involves converting complex cognitive operations (which take 8-10 s) into simple cognitive operations (which take 1-2 s)" (Leach, 2004)

This observation explains the benefits of using practised memory items to ensure a correct immediate response in time-critical situations. It may be worth researching if training in Watt's articulated high-level surprise management workflow as a high-level memory item and integrating it in the middle of a most critical situations boundary model (Figure 31) could offer an effective and holistic training solution that could benefit a much broader spectrum of potential abnormal and emergency situations. This approach may provide an alternative integrated view on pilot training, potentially enabling the pilots to better fly and navigate (Airbus, 2019a) from the initial onset of a failure all the way down to reach the desired outcome, as suggested by Hollnagel & Woods (2005): "Instead of trying to solve the specific problems one by one, the solution lies in understanding the common root of the problems, and to overcome this by proposing an alternative, integrated view." (Hollnagel & Woods, 2005, p.19)

I also believe that training pilots in a combined articulated high-level surprise management workflow and a management comfort/confidence envelope bounded by most critical situations would complement and benefit the new Evidence Based Training (EBT) approach. The EBT is described in the EBT ICAO Manual Document 9995 (ICAO, 2013).

Many airlines are currently implementing this new approach to pilot simulator training. Based on evidential statistics, EBT aims to improve pilots' response to surprise situations by developing the following competencies:

- Application of procedures
- Communication
- Flight Path Management, automation
- Flight Path Management, manual control
- Leadership and Teamwork
- Problem Solving and Decision Making
- Situation Awareness
- Workload Management

These competencies "encompass what was previously known as both technical and non-technical knowledge, skills and attitudes, aligning the training content with the actual competencies necessary in the context of contemporary aviation" (ICAO, 2013). They are assessed using the behavioural indicators described in Appendix 1 of the EBT ICAO Manual (ICAO, 2013).

To better achieve some of the behavioural indicators associated with EBT competencies, pilots might benefit from using judgment heuristics through which they can spare the mental capacity required for managing other tasks and distractions.

To link the results of this research with the potential benefits of implementing judgment heuristics training in EBT, let us look at the complete list of behavioural indicators associated with four competencies that are relevant to the simulation scenario used in this research: Workload Management, Situational Awareness, Problem Solving and Decision Making, and Flight Path Management with manual control (ICAO, 2013, Appendix 1):

Competency & Competency description	Behavioural indicators
Workload Management Manages available resources efficiently to prioritize and perform tasks in a timely manner under all circumstances.	• Maintains self-control in all situations • Plans, prioritizes and schedules tasks effectively • Manages time efficiently when carrying out tasks • Offers and accepts assistance, delegates when necessary and asks for help early • Reviews, monitors and cross-checks actions conscientiously • Verifies that tasks are completed to the expected outcome • Manages and recovers from interruptions, distractions, variations and failures effectively
Situation Awareness Perceives and comprehends all of the relevant information available and anticipates what could happen that may affect the operation.	• Identifies and assesses accurately the state of the and its systems • Identifies and assesses accurately the 's vertical and lateral position, and its anticipated flight path. • Identifies and assesses accurately the general environment as it may affect the operation • Keeps track of time and fuel • Maintains awareness of the people involved in or affected by the operation and their capacity to perform as expected • Anticipates accurately what could happen, plans and stays ahead of the situation • Develops effective contingency plans based upon potential threats • Identifies and manages threats to the safety of the and people. • Recognizes and effectively responds to indications of reduced situation awareness
Problem Solving and Decision Making Accurately identifies risks and resolves problems. Uses the appropriate decision-making processes	• Seeks accurate and adequate information from appropriate sources • Identifies and verifies what and why things have gone wrong • Employ(s) proper problem-solving strategies • Perseveres in working through problems without reducing safety • Uses appropriate and timely decision-making processes • Sets priorities appropriately • Identifies and considers options effectively • Monitors, reviews, and adapts decisions as required • Identifies and manages risks effectively • Improvises when faced with unforeseeable circumstances to achieve the safest outcome

Flight Path Management, manual control Controls the flight path through manual flight, including appropriate use of flight management system(s) and flight guidance systems.	• Controls the manually with accuracy and smoothness as appropriate to the situation • Detects deviations from the desired trajectory and takes appropriate action • Contains the within the normal flight envelope • Controls the safely using only the relationship between attitude, speed and thrust • Manages the flight path to achieve optimum operational performance • Maintains the desired flight path during manual flight whilst managing other tasks and distractions • Selects appropriate level and mode of flight guidance systems in a timely manner considering phase of flight and workload • Effectively monitors flight guidance systems including engagement and automatic mode transitions

Table 17. EBT competencies and associated behavioural indicators (ICAO, 2013, Appendix 1)

Following the crew familiarization with judgment heuristics to manage an ALL ENG FAIL situation at cruising altitude, the comparative simulations and questionnaire results obtained in this experimental research may indicate an improvement in most behavioural indicators associated with the four EBT competencies presented in Table 11.

8 Conclusions

The scientific object of this research undertaken following an experimental design methodology was the Airbus A320 ALL ENG FAIL QRH procedure (Airbus, 2019d, ABN 19.01A). The experimental variable was represented by judgment heuristics that integrate tacit knowledge, which is passed verbally from pilot to pilot but is not written anywhere. The purpose of this research was to observe how the ALL ENG FAIL manufacturer procedure contributes to the management of an ALL ENGINES FAIL situation at cruising altitudes and to investigate whether the addition of judgment heuristics impacts the desired outcome defined as landing and stopping on an available runway.

The research results show that the QRH procedure induces pilots into a scrambled control mode (Hollnagel & Woods, 2005) as it does not offer pilots effectively operationalizable navigational information. Assuming that one of the manufacturer procedure's purpose is to enable pilots to make a successful forced landing on a reachable runway if the engines cannot be restarted, a reconsideration of the procedure design is necessary. It should offer the pilots a coherent, easy to calculate and monitor gliding information, commensurate with their contextually foreseeable cognitive workload abilities and limitations (Jarvis et al., 2014; Landman et al., 2017a; Moriarty, 2015; Rankin et al., 2016; Wilson & Sharples, 2015).

The judgment heuristics improved the management of the situation by effectively simplifying the navigational calculations required to control the glide, offering straight-in and circling approach options familiar to what the pilots have been taught and experienced throughout their flight careers (Clewley & Nixon, 2019). These improvements could be detected both on the basis of the pilots' self-assessment and on the basis of the fact that the addition of judgement heuristics has led to an increased number of successful landings during the simulations. The simplified calculations offered by the judgment heuristics provide a more restrictive gliding distance answer. In contrast, the higher cognitive resources demanded by the manufacturer procedure may offer a greater and more accurate distance. After being briefed on and having practised the use of judgment heuristics, all the pilots participating in this research preferred to use heuristics to calculate and monitor their navigational profile. Their choice of good enough simplicity over more real complexity represents an example of Efficiency-Thoroughness Trade-Off (ETTO) (Hollnagel, 2009) and might be useful to consider during an eventual procedure re-design.

The benefits of using judgment heuristics to control the glide are visible, significant, and more accentuated in the latter stages of the descent when time and options narrow down to zero at touch down. This conclusion is clearly indicated by the pilots' ratings of their perceived situational awareness (knowledge of the aircraft energy state and ability to anticipate and accommodate trends), the effort required to manage the cognitive workload, and decision-making rating scales (Gawron, 2008) which were part of the comparative questionnaires that followed the observed comparative simulations.

The results of the present study suggest directions for further research, exploring the potential benefits of implementing training heuristics in official training programs, especially in light of the fact that, during the initial interviews, the pilots indicated several abnormal and emergency situations that they perceive as most critical. Training pilots in heuristics that would help them manage these situations up to a level of proficiency that would boost their confidence in their abilities to maintain control of the aeroplane, together with an articulated high-level surprise management workflow (M. Watt, personal communication, 22 April 2020), may have a positive impact on pilots' cognitive workload, situational awareness, or decision-making processes (Jarvis et al., 2014; Moriarty, 2015; Neisser, 1976) required to make the necessary trade-offs (Hollnagel, 2009) and their subsequent actions. Such training could easily complement the already existing Evidence-Based approach (ICAO, 2013).

9 References

Adriaensen, A., Patriarca, R., Smoker, A., & Bergström, J. (2019). A socio-technical analysis of functional properties in a joint cognitive system: a case study in an aircraft cockpit. *Ergonomics*. https://doi.org/10.1080/00140139.2019.1661527

Airbus. (2004a). *Flight Operations Briefing Notes Human Factors Aspects in Incidents / Accidents - Revision 2*. 1–10. https://doi.org/FLT_OPS – HUM_PER - SEQ01 - REV02 – MAY 2004

Airbus. (2004b). *Flight Operations Briefing Notes Human Performance Flight Operations Briefing Notes - Revision 3*. 1–11.

Airbus. (2015). *A320 Flight Manual - Revision 24-NOV-2015*.

Airbus. (2019a). *A320-A321 Flight Crew Operating Manual (FCOM) Revision 04-SEP-2019*.

Airbus. (2019b). *A320-A321 Flight Crew Techniques Manual (FCTM). Revision 04-SEP-19.* 492.

Airbus. (2019c). *A320-A321 Minimum Equipment List (MEL) Revision 1- DEC-2019*.

Airbus. (2019d). *A320-A321 Quick Reference Handbook (QRH) 04 SEP 2019*. (1).

Airbus. (2019e). *A320 Flight Crew Training Standards Revision 12.11.2019*.

All Engine Powerloss. (n.d.). Retrieved February 19, 2021, from Aviation Safety Network website: https://aviation-safety.net/database/events/dblist.php?Event=ACEL&lang=&page=1

Allspaw, J. (2015). *TRADE-OFFS UNDER PRESSURE: HEURISTICS AND OBSERVATIONS OF TEAMS RESOLVING INTERNET SERVICE OUTAGES*. Lund: Lund University.

Amalberti, R. (2001). The paradoxes of almost totally safe transportation systems. *Safety Science*, *37*(2–3), 109–126. https://doi.org/10.1016/S0925-7535(00)00045-X

Bombardier. (2019). *CRJ 900 Quick Reference Handbook, Volume 2*.

British Aerospace. (2007). *Avro 146-RJ Flight Crew Operation Manual, Volume 3, Part 3, Abnormal and Emergency Checklists*. *3*.

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*.

Charalambides, P., Tyrrell, B., & Norden, C. (2017). Preparing Flight Crews to Face Unexpected Events. *Safety First #23*, (January 2017).

Clewley, R., & Nixon, J. (2019). Understanding pilot response to flight safety events using categorisation theory. *Theoretical Issues in Ergonomics Science*, *20*(5), 572–589. https://doi.org/10.1080/1463922X.2019.1574929

de Vries, L., & Bligård, L. O. (2019). Visualising safety: The potential for using sociotechnical systems models in prospective safety assessment and design. *Safety Science*, *111*, 80–93. https://doi.org/10.1016/j.ssci.2018.09.003

Degani, A., & Wiener, E. L. (1990). *The human factors of flight deck checklists: The normal checklist. NASA Technical Memorandum #177549*. (May), 70.

DeLisi, J. (2018). National transportation safety board. *63rd Annual Business Aviation Safety Summit, BASS 2018*, 161–179. https://doi.org/10.4135/9781452241067.n23

EASA. (2016). *Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex III - Part-ORO*.

EASA. (2018). *Safety Issues as Fact Sheet*. Retrieved from https://www.easa.europa.eu/document-library/research-reports/easarepresea20153

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*. https://doi.org/10.1518/001872095779049543

European Union. (2011). *COMISSION REGULATION (EU) of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council*.

FAA. (1996). *The Interfaces Between Flightcrews and Modern Flight Deck Systems*.

Gawron, V. J. (2008). Human Performance, Workload, and Situational Awareness Measures Handbook. *Human Performance, Workload, and Situational Awareness Measures Handbook*, *№3*, c.30. https://doi.org/10.1201/9781420064506

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal*, *26*(2), 91–108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Hollnagel, E. (2009). The ETTO principle: Efficiency-thoroughness trade-off: Why things that go right sometimes go wrong. In *The ETTO Principle: Efficiency-Thoroughness Trade-Off: Why Things That Go Right Sometimes Go Wrong*.

Hollnagel, E., & Woods, D. D. (2005). *Joint Cognitive Systems*.

ISO. (1975). Standard Atmosphere, ISO 2533:1975. *International Standard Organisation*.

Jarvis, S., Budenberg, C., Carver, P., Cruse, G., Mann, C., Field, P., … Lawrence, K. (2014). CAP737 - Flight-Crew Human Factors Handbook. *Intelligence, Strategy and Policy*. Retrieved from https://publicapps.caa.co.uk/docs/33/CAP 737 DEC16.pdf

Katerinakis, T. (2019). *The Social Construction of Knowledge in Mission-Critical Environments*. https://doi.org/10.1007/978-3-319-91014-7

Klein, G. a. (1993). A recognition-primed decision (RPD) model of rapid decision making. *Decision Making in Action: Models and Methods*. https://doi.org/10.1002/bdm.3960080307

Landman, A., Groen, E. L., van Paassen, M. M. (René., Bronkhorst, A. W., & Mulder, M. (2017a). Dealing With Unexpected Events on the Flight Deck: A Conceptual Model of Startle and Surprise. *Human Factors*, *59*(8), 1161–1172. https://doi.org/10.1177/0018720817723428

Landman, A., Groen, E. L., van Paassen, M. M. (René., Bronkhorst, A. W., & Mulder, M. (2017b). The Influence of Surprise on Upset Recovery Performance in Airline Pilots. *International Journal of Aerospace Psychology*, *27*(1–2), 2–14. https://doi.org/10.1080/10508414.2017.1365610

Leach, J. (2004). Why people “freeze” in an emergency: Temporal and cognitive constraints on survival responses. *Aviation Space and Environmental Medicine*, *75*(6), 539–542. Retrieved from http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L38669452

Moriarty, D. (2015). Practical Human Factors for Pilots. In *Practical Human Factors for Pilots*. https://doi.org/10.1016/C2013-0-13582-9

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology.* New York, NY, US: W H Freeman/Times Books/ Henry Holt & Co.

Plant, K. L., & Stanton, N. A. (2015). The process of processing: exploring the validity of Neisser's perceptual cycle model with accounts from critical decision-making in the cockpit. *Ergonomics*, *58*(6), 909–923. https://doi.org/10.1080/00140139.2014.991765

Plant, K. L., & Stanton, N. A. (2016). Distributed Cognition and Reality: How Pilots and Crews Make Decisions. In *Distributed Cognition and Reality*. https://doi.org/10.1201/9781315577647

Rankin, A., Ekstrom, E., Sjolin, V., Rogier, W., Stepniczka, I., & Eder, M. (2015). Final report of research methods and results. In *Man4Gen*. https://doi.org/10.1016/j.arthro.2005.01.001

Rankin, A., Woltjer, R., & Field, J. (2016). Sensemaking following surprise in the cockpit—a re-framing problem. *Cognition, Technology and Work*, *18*(4), 623–642. https://doi.org/10.1007/s10111-016-0390-2

Rankin, A., Woltjer, R., Field, J., & Woods, D. (2013). "Staying ahead of the aircraft" and Managing Surprise in Modern Airliners. *Proceedings of the 5th Resilience Engineering Association Symposium*, 209–214. Retrieved from http://www.resilience-engineering-association.org/download/resources/symposium/symposium-2013/Rankin et al. (REA 2013). "Staying ahead of the aircraft" and Managing Surprise in Modern Airliners.pdf

Ross, A., & Willson, V. L. (2017). Basic and Advanced Statistical Tests. In *Basic and Advanced Statistical Tests*. https://doi.org/10.1007/978-94-6351-086-8

Rules of thumb. (n.d.). Retrieved from Skybrary website: passed as verbal knowledge from pilot to pilot, are not present in any Airbus or training written documentation.

Shorrock, S. (2020). DECISION-MAKING AT WORK: QF32 AND YOU. *HindSight 29*.

Talone, A. B., & Jentsch, F. (2015). *Evaluating Startle , Surprise , and Distraction : an Analysis of Aircraft Incident and Accident Reports*. 278–283.

Vaughan, D. (2004). Theorizing Disaster: Analogy, historical ethnography, and the Challenger accident. *Ethnography*, *5*(3), 315–347. https://doi.org/10.1177/1466138104045659

Wilson, J. R., & Sharples, S. (2015). *EVALUATION OF HUMAN WORK FOURTH EDITION*. CRC Press, Taylor & Francis Group.

Woods, D. D., & Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*. https://doi.org/10.1080/00140130701223774

Woods, D. D., & Sarter, N. B. (n.d.). *Learning from Automation Surprises and "Going Sour" Accidents*. https://doi.org/10.1007/BF02126635

Appendix 1 – The Airbus A320 'ALL ENG FAIL' QRH procedure

A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	19.02A 16 JUL 19

ALL ENG FAIL (Cont'd)

- **If engine relight can be attempted:**

  ENG MODE sel..IGN

  - **Approaching or below FL 300: Windmill Relight**

    ALL ENG MASTERS..OFF 30 S THEN ON

    ENGs RELIGHT...TRY REGULARLY

    Windmill relight attempts can be repeated until successful, or until the APU bleed is available.

    APU (below FL 250)...START

    - **If APU available and windmill relight unsuccessful : Starter Assisted Relight below FL 200**

      ALL ENG MASTERS..OFF

      OPTIMUM SPEED: GREEN DOT (REFER TO TABLE BELOW)

GREEN DOT SPEED WITH ALL ENGINES INOPERATIVE (kt)			
Gross Weight (1 000 kg)	***At or below FL 200***	***FL 300***	***FL 400***
78	*236*	*246*	*256*
76	*232*	*242*	*252*
72	*224*	*234*	*244*
68	*216*	*226*	*236*
64	*208*	*218*	*228*
60	*200*	*210*	*220*
56	*192*	*202*	*212*
52	*184*	*194*	*204*
48	*176*	*186*	*196*
44	*168*	*178*	*188*
40	*160*	*170*	*180*

      WING ANTI ICE...OFF

      APU BLEED..ON

      ENG MASTER (one at a time)..ON

      Between each attempt to relight the same engine, wait at least 30 s with the associated ENG MASTER lever set to OFF.

  SPEED BRAKES AVAILABLE

  - **When below 10 000 ft AGL:**

    PREPARE CABIN AND COCKPIT

    RAM AIR...ON

    BARO REF (if avail)..SET

    COMMERCIAL...OFF

    ELT (when conditions permit)..ON

    ENGs RELIGHT...TRY REGULARLY

    USE RUDDER WITH CARE

  - **If ditching anticipated:**

    Refer to Ditching procedure - 19.04A

WZZ MSN 06683 **HA-LYT**

A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	19.02B 16 JUL 19

ALL ENG FAIL (Cont'd)

- **If forced landing anticipated:**
  Refer to Forced landing procedure - 19.05A

WZZ MSN 06683 **HA-LYT**

A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	19.03A 16 JUL 19

ALL ENG FAIL (Cont'd)

- **If engine relight cannot be attempted:**

  OPTIMUM SPEED: GREEN DOT (REFER TO TABLE BELOW)

GREEN DOT SPEED WITH ALL ENGINES INOPERATIVE (kt)			
Gross Weight (1 000 kg)	At or below FL 200	FL 300	FL 400
78	236	246	256
76	232	242	252
72	224	234	244
68	216	226	236
64	208	218	228
60	200	210	220
56	192	202	212
52	184	194	204
48	176	186	196
44	168	178	188
40	160	170	180

GLIDING DISTANCE : 2.5 NM / 1000 FT

GLIDING DISTANCE AT GREEN DOT: 2.5 NM / 1000 FT (400 FT/NM) NO WIND			
Flight Level	FL 200	FL 300	FL 400
Distance (NM)	50	75	100

APU (below FL 250)..START
WING ANTI ICE...OFF
APU BLEED (below FL 200)...ON

SPEED BRAKES AVAILABLE

- **Below 10 000 ft AGL:**

  PREPARE CABIN AND COCKPIT
  RAM AIR..ON
  BARO REF (if avail)..SET
  COMMERCIAL..OFF
  ELT (when conditions permit)..ON

  USE RUDDER WITH CARE

- **If ditching anticipated:**

  Refer to Ditching procedure - 19.04A

- **If forced landing anticipated:**

  Refer to Forced landing procedure - 19.05A

WZZ MSN 06683 **HA-LYT**

A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	19.04A 16 JUL 19

ALL ENG FAIL (Cont'd)

- **If ditching anticipated:**

  MIN RAT SPEED : 140 KT

  GPWS SYS..OFF

  GPWS TERR..OFF

  - **At appropriate altitude (above 3 000 ft AGL), configure aircraft for ditching:**

    FOR LANDING : USE FLAP 2

    KEEP LANDING GEAR UP

    VAPP..DETERMINE

Gross Weight (1000 kg)	40	50	60	70	80	90	95
VAPP (kt)	150	150	163	173	183	193	198

  - **At 2 000 ft AGL:**

    CABIN CREW..NOTIFY FOR DITCHING

    DITCHING pb..ON

    Ditch the aircraft parallel to the swell. If that causes a strong crosswind, ditch the aircraft into the wind.

  - **At 500 ft AGL:**

    BRACE FOR IMPACT..ORDER

    TOUCH DOWN AT MIN V/S

    TARGET PITCH ATT 11 °

  - **At touchdown:**

    ALL ENG MASTERS..OFF

    APU MASTER SW..OFF

  - **After ditching:**

    ATC (VHF 1)..NOTIFY

    ALL FIRE pb (ENGs & APU)..PUSH

    ALL AGENT (ENGs & APU)..DISCH

    EVACUATION..INITIATE

WZZ MSN 06683 **HA-LYT**

WIZZ A318/A319/A320/A321 QUICK REFERENCE HANDBOOK	ABNORMAL AND EMERGENCY PROCEDURES	19.05A 16 JUL 19

ALL ENG FAIL (Cont'd)

- **If forced landing anticipated:**
  DESCENT SLOPE (CONF 2, L/G DOWN) : 1.6 NM / 1000 FT (600 FT/NM)
  MIN RAT SPEED: 140 KT
  GPWS SYS...OFF
  GPWS TERR..OFF
  - **At appropriate altitude (above 3 000 ft AGL), configure aircraft for landing:**
    FOR LANDING : USE FLAP 2
    Only slats extend, and slowly.
    VAPP..DETERMINE

Gross Weight (1000 kg)	40	50	60	70	80	90	95
VAPP (kt)	150	150	163	173	183	193	198

  - **When in CONF 2 and VAPP:**
    GRAVITY GEAR EXTN handcrank...........................PULL AND TURN
    Flight controls revert to direct law at landing gear extension.
    MAN PITCH TRIM NOT AVAILABLE
    Disregard the "USE MAN PITCH TRIM" message on the PFD.
    - **When L/G downlocked:**
      L/G lever..DOWN
      APPROACH SPEED..ADJUST
      Adjust the speed to the above-mentioned VAPP. However, to reach the landing field or runway, it is possible to increase the approach speed.

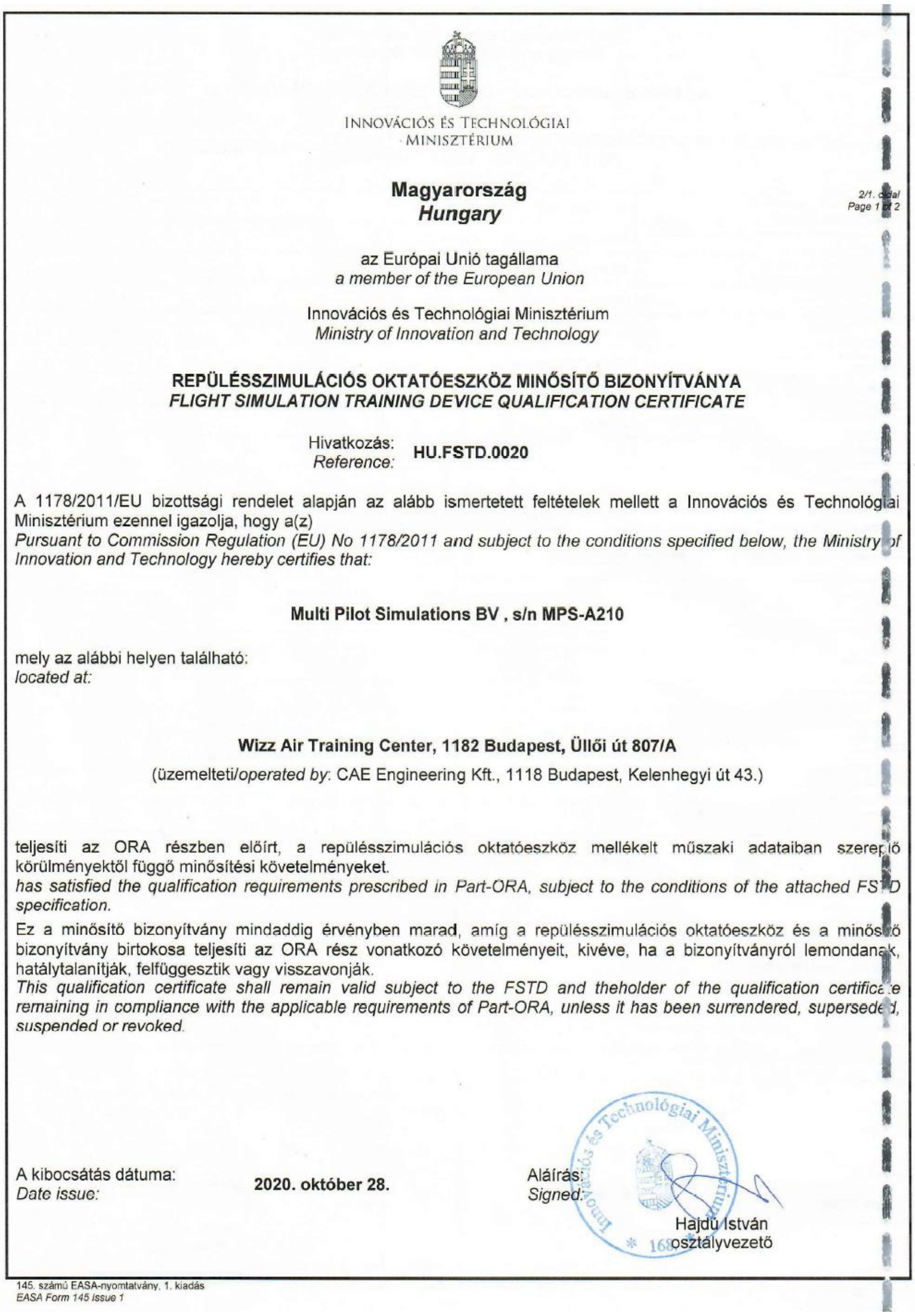
    SPLRs...ARM
    MAX BRK PR : 1 000 PSI
  - **At 2 000 ft AGL:**
    CABIN CREW..............................NOTIFY FOR LANDING
  - **At 500 ft AGL:**
    BRACE FOR IMPACT..ORDER
  - **At touchdown:**
    ALL ENG MASTERS..OFF
    APU MASTER SW..OFF
    BRAKES ON ACCU ONLY
  - **When aircraft stopped:**
    PARKING BRK...ON
    ATC (VHF 1)...NOTIFY
    ALL FIRE pb (ENGs & APU)....................................PUSH
    ALL AGENT (ENGs & APU).....................................DISCH
    - **If evacuation required:**
      EVACUATION...INITIATE

WZZ MSN 06683 **HA-LYT**

Appendix 2 – Technical details of simulators used

The Wizz Air certified simulator in Budapest

The certification documents of the Wizz Air simulator are:



INNOVÁCIÓS ÉS TECHNOLÓGIAI MINISZTÉRIUM

2/1. oldal
Page 1 of 2

Magyarország
Hungary

az Európai Unió tagállama
a member of the European Union

Innovációs és Technológiai Minisztérium
Ministry of Innovation and Technology

REPÜLÉSSZIMULÁCIÓS OKTATÓESZKÖZ MINŐSÍTŐ BIZONYÍTVÁNYA
FLIGHT SIMULATION TRAINING DEVICE QUALIFICATION CERTIFICATE

Hivatkozás: *Reference:* **HU.FSTD.0020**

A 1178/2011/EU bizottsági rendelet alapján az alább ismertetett feltételek mellett a Innovációs és Technológiai Minisztérium ezennel igazolja, hogy a(z)
Pursuant to Commission Regulation (EU) No 1178/2011 and subject to the conditions specified below, the Ministry of Innovation and Technology hereby certifies that:

Multi Pilot Simulations BV , s/n MPS-A210

mely az alábbi helyen található:
located at:

Wizz Air Training Center, 1182 Budapest, Üllői út 807/A
(üzemelteti/*operated by*: CAE Engineering Kft., 1118 Budapest, Kelenhegyi út 43.)

teljesíti az ORA részben előírt, a repülésszimulációs oktatóeszköz mellékelt műszaki adataiban szereplő körülményektől függő minősítési követelményeket.
has satisfied the qualification requirements prescribed in Part-ORA, subject to the conditions of the attached FSTD specification.

Ez a minősítő bizonyítvány mindaddig érvényben marad, amíg a repülésszimulációs oktatóeszköz és a minősítő bizonyítvány birtokosa teljesíti az ORA rész vonatkozó követelményeit, kivéve, ha a bizonyítványról lemondanak, hatálytalanítják, felfüggesztik vagy visszavonják.
This qualification certificate shall remain valid subject to the FSTD and theholder of the qualification certificate remaining in compliance with the applicable requirements of Part-ORA, unless it has been surrendered, superseded, suspended or revoked.

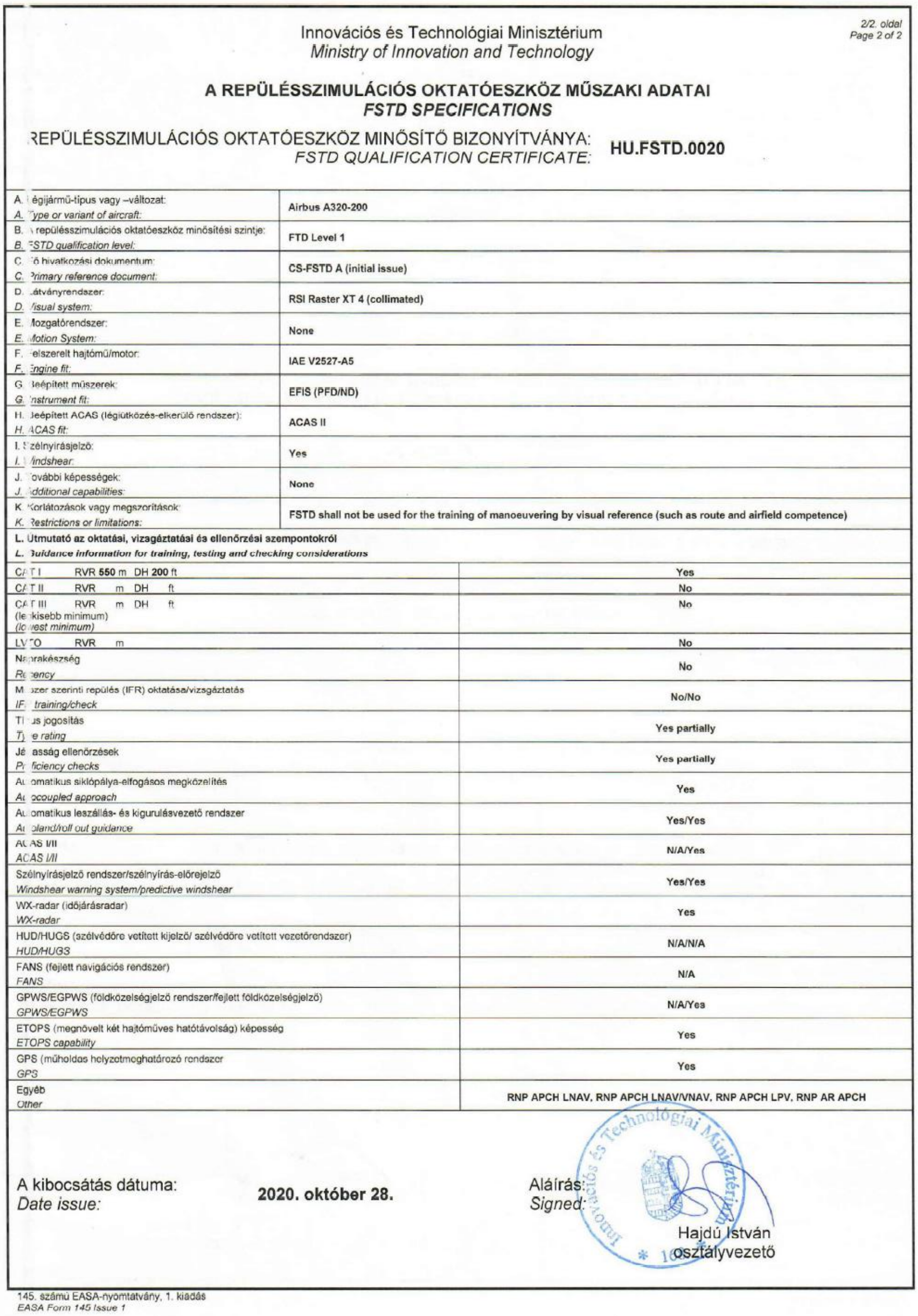
A kibocsátás dátuma: *Date issue:* **2020. október 28.**

Aláírás: *Signed:*

Hajdú István
osztályvezető

145. számú EASA-nyomtatvány, 1. kiadás
EASA Form 145 Issue 1

Figure 32. Simulator certification document



2/2. oldal
Page 2 of 2

Innovációs és Technológiai Minisztérium
Ministry of Innovation and Technology

A REPÜLÉSSZIMULÁCIÓS OKTATÓESZKÖZ MŰSZAKI ADATAI
FSTD SPECIFICATIONS

REPÜLÉSSZIMULÁCIÓS OKTATÓESZKÖZ MINŐSÍTŐ BIZONYÍTVÁNYA:
FSTD QUALIFICATION CERTIFICATE: **HU.FSTD.0020**

A. égijármű-típus vagy –változat: *A. ype or variant of aircraft:*	**Airbus A320-200**
B. repülésszimulációs oktatóeszköz minősítési szintje: *B. STD qualification level:*	**FTD Level 1**
C. ő hivatkozási dokumentum: *C. Primary reference document:*	**CS-FSTD A (initial issue)**
D. átványrendszer: *D. isual system:*	**RSI Raster XT 4 (collimated)**
E. lozgatórendszer: *E. Motion System:*	**None**
F. elszerelt hajtómű/motor: *F. Engine fit:*	**IAE V2527-A5**
G. Beépített műszerek: *G. nstrument fit:*	**EFIS (PFD/ND)**
H. Beépített ACAS (légiütközés-elkerülő rendszer): *H. ACAS fit:*	**ACAS II**
I. Szélnyirásjelző: *I. Vindshear:*	**Yes**
J. További képességek: *J. dditional capabilities:*	**None**
K. Korlátozások vagy megszorítások: *K. Restrictions or limitations:*	**FSTD shall not be used for the training of manoeuvering by visual reference (such as route and airfield competence)**

L. Útmutató az oktatási, vizsgáztatási és ellenőrzési szempontokról
L. Guidance information for training, testing and checking considerations

CAT I RVR **550** m DH **200** ft	**Yes**
CAT II RVR m DH ft	**No**
CAT III RVR m DH ft (legkisebb minimum) *(lowest minimum)*	**No**
LVTO RVR m	**No**
Naprakészség *Recency*	**No**
Műszer szerinti repülés (IFR) oktatása/vizsgáztatás *IFR training/check*	**No/No**
Típus jogosítás *Type rating*	**Yes partially**
Jártasság ellenőrzések *Proficiency checks*	**Yes partially**
Automatikus siklópálya-elfogásos megközelítés *Autocoupled approach*	**Yes**
Automatikus leszállás- és kigurulásvezető rendszer *Autoland/roll out guidance*	**Yes/Yes**
ACAS I/II *ACAS I/II*	**N/A/Yes**
Szélnyírásjelző rendszer/szélnyírás-előrejelző *Windshear warning system/predictive windshear*	**Yes/Yes**
WX-radar (időjárásradar) *WX-radar*	**Yes**
HUD/HUGS (szélvédőre vetített kijelző/ szélvédőre vetített vezetőrendszer) *HUD/HUGS*	**N/A/N/A**
FANS (fejlett navigációs rendszer) *FANS*	**N/A**
GPWS/EGPWS (földközelségjelző rendszer/fejlett földközelségjelző) *GPWS/EGPWS*	**N/A/Yes**
ETOPS (megnövelt két hajtóműves hatótávolság) képesség *ETOPS capability*	**Yes**
GPS (műholdas helyzetmeghatározó rendszer *GPS*	**Yes**
Egyéb *Other*	**RNP APCH LNAV, RNP APCH LNAV/VNAV, RNP APCH LPV, RNP AR APCH**

A kibocsátás dátuma:
Date issue: **2020. október 28.**

Aláírás:
Signed:

Hajdú István
osztályvezető

145. számú EASA-nyomtatvány, 1. kiadás
EASA Form 145 Issue 1

Figure 33. Simulator certification document

The simulator can generate horizontal path profiles and only short final approach vertical profiles as follow:

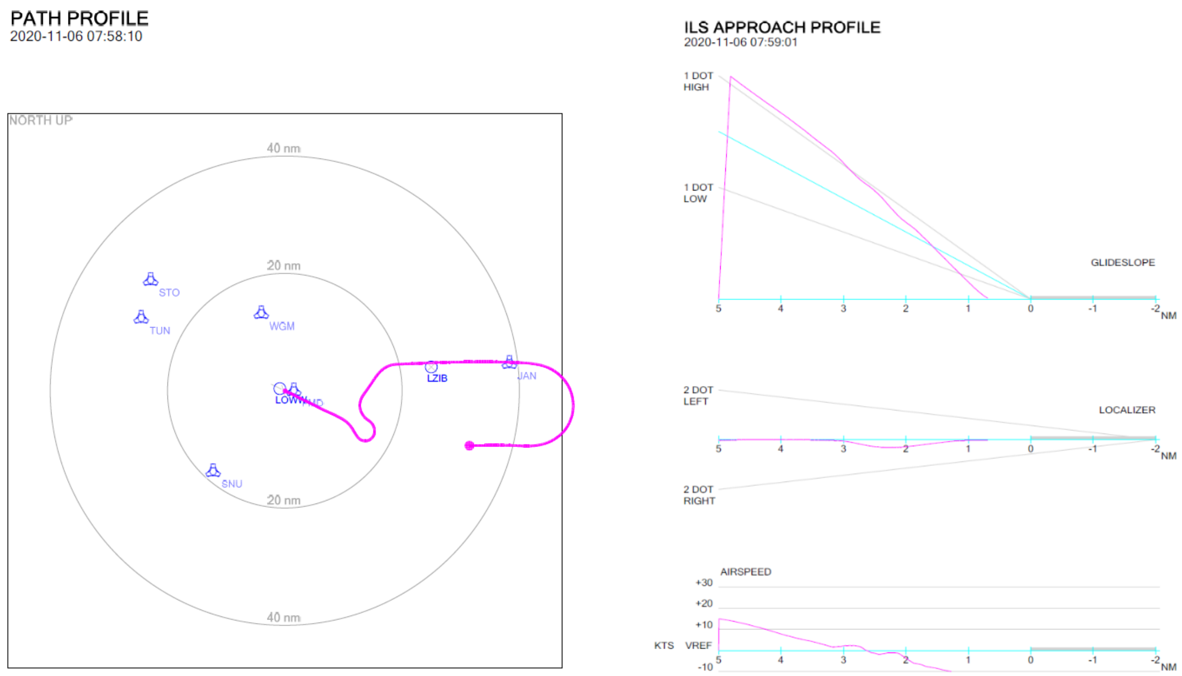


Figure 34. Simulation path and ILS approach profiles – Budapest simulator

The FlightX non-certified simulator in Cluj-Napoca

The technical details of the Flight Experience (FlightX) non-certified simulator are:

- SKALARKI ELECTRONICS A320 cockpit components and SKALARKIIO Profiler 5.1.3 (https://www.skalarki-electronics.eu/)
- Lockheed Martin Prepar3D v4.4 platform (https://www.prepar3d.com/)
- ProSim-AR ProSimA320 v1.36 suite for systems simulation can simulate all mandatory ATA failures and even more for a total of 320 failures. (https://prosim-ar.com/prosima320/)
- 210-degrees immersive field of view, ensured by three projectors and Fly Elise-ng Immersive Display PRO v4.3.0 software (https://fly.elise-ng.net/immersive-display-pro/)
- simFDR is a software tool that connects to Prepar3D v4 to extract and save relevant flight parameters. It does this the same way a Digital Flight Data Recorder would receive and store data from system sensors in a real aircraft (simfdr.com).

The simulator can generate output data in the following formats:

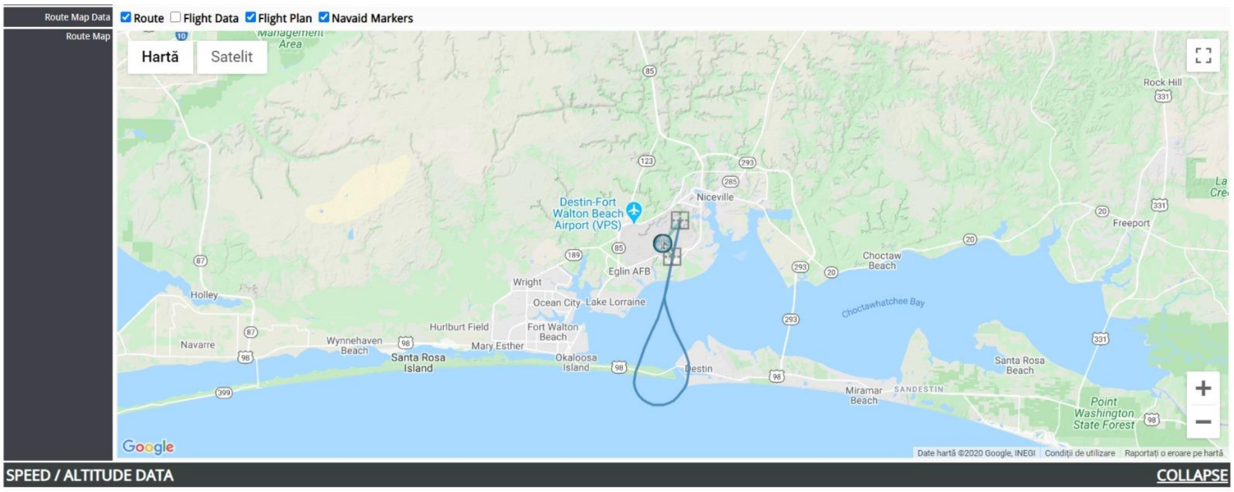


Figure 35. Simulation path view - Cluj-Napoca simulator

FLIGHT WZZ123 FLOWN ON 06/18/2020 BY MYTESTACCOUNT10	
Submitted on	06/18/2020 14:42
Callsign	WZZ123 - Share
Equipment Type	**A320** Airbus A320
Departed from	Eglin AFB (**KVPS**)
Arrived at	Eglin AFB (**KVPS**)
Alternate	Robins AFB (**KWRB**)
Simulator	**Lockheed-Martin Prepar3D/64**
Flight Distance	**0 Nautical Miles**
Logged Time	0.1 hours
Flight Data	Download simFDR data into CSV | KML | JSON | XML
simFDR Client	Build 21 [64-bit]
FDE File	A320.air
Aircraft SDK	Generic
Start Time	**06/18/2020 14:34**
Taxi from Gate	06/18/2020 14:34, 141,810 lbs total, 10,978 lbs fuel
Takeoff Time	**06/18/2020 14:35**, (1 minutes after start) Zoom to Takeoff
Takeoff Runway	**19** (Asphalt - 10,024 feet, takeoff run 4,777 feet)
Takeoff Information	164 knots, 86.1% N_1, 141,658 lbs total, 10,826 lbs fuel
Landing Time	**06/18/2020 14:41**, (7 minutes after start) Zoom to Landing
Landing Runway	**01** (Asphalt - 10,024 feet, 613 feet from threshold)
Landing Information	116 knots, -457 feet/minute, 29.9% N_1, 140,973 lbs total, 10,141 lbs fuel
Arrival Time	**06/18/2020 14:42**, (7 minutes after start)
Arrival Information	140,942 lbs total, 10,110 lbs fuel
Flight Time	**00:06**, block time 00:07
Frame Rate	25.8 average frames/second
Flight Route	KVPS KVPS
Route Map Data	**Route** **Flight Data** **Flight Plan** **Navaid Markers**

Figure 36. Simulator data output – Cluj-Napoca simulator

Date/Time	Latitude	Longitude	Altitude	Heading	Air Speed	Ground Speed	Vertical Speed	N1	N2	Bank	Pitch	Flaps	WindSpeed	WindHdg	Temperature	Pressure	FuelFlow	Fuel	Gs	AOA
06/18/2020 14:34:0	304993	-865113	101	194	0	0	0	165	496	0	-2		0	0	15	0	688	11001	####	-99900
06/18/2020 14:34:5	304993	-865113	101	194	3	3	0	352	772	0	-1	3	0	0	15	0	1686	10977	####	-127
06/18/2020 14:34:5	304991	-865113	101	194	15	15	0	743	925	0	0	3	0	0	15	0	6667	10969	####	42
06/18/2020 14:35:0	304983	-865115	101	193	48	48	0	837	955	-1	2	3	0	0	15	0	9055	10942	998	233
06/18/2020 14:35:0	304974	-865117	101	195	68	68	0	829	951	0	1	3	0	0	15	0	8649	10926	####	48
06/18/2020 14:35:0	304961	-865121	101	196	87	87	0	845	958	0	-1	3	0	0	15	0	8792	10910	####	-142
06/18/2020 14:35:1	304946	-865125	101	193	106	106	0	849	959	1	-2	3	0	0	15	0	8558	10891	####	-203
06/18/2020 14:35:1	304927	-865129	101	194	124	123	1	855	961	0	2	3	0	0	15	0	8388	10877	998	241
06/18/2020 14:35:1	304906	-865134	101	194	140	140	0	861	964	0	2	3	0	0	15	0	8262	10858	####	195
06/18/2020 14:35:2	304883	-865140	102	194	156	155	27	859	963	0	39	3	0	0	15	0	8026	10838	989	3640
06/18/2020 14:35:2	304864	-865145	103	194	165	165	29	861	964	0	73	3	0	0	15	0	7944	10826	####	7015
06/18/2020 14:35:2	304844	-865149	119	194	172	172	457	864	965	-2	94	3	0	0	15	0	7892	10813	####	7039
06/18/2020 14:35:2	304824	-865154	164	194	178	177	1173	866	966	-2	118	3	0	0	15	0	7854	10801	####	7026
06/18/2020 14:35:3	304803	-865159	248	194	181	179	2060	866	965	-1	133	3	0	0	14	0	7790	10785	####	5933
06/18/2020 14:35:3	304782	-865165	357	194	183	181	2545	868	966	-1	130	3	0	0	14	0	7788	10775	987	4823
06/18/2020 14:35:3	304761	-865170	471	194	185	183	2655	868	966	-1	128	3	0	0	14	0	7720	10762	971	4598
06/18/2020 14:35:4	304739	-865175	587	194	187	186	2704	866	965	-1	127	3	0	0	14	0	7638	10746	973	4456
06/18/2020 14:35:4	304717	-865180	706	194	190	189	2760	870	966	-1	125	3	0	0	13	0	7648	10733	974	4217
06/18/2020 14:35:4	304695	-865185	825	194	193	192	2815	868	965	-1	123	3	0	0	13	0	7556	10723	978	3995
06/18/2020 14:35:4	304673	-865191	944	194	195	194	2865	829	948	-1	121	3	0	0	13	0	6770	10709	973	3774
06/18/2020 14:35:5	304651	-865196	1065	194	195	195	2875	796	936	-1	121	3	0	0	13	0	6100	10696	979	3806
06/18/2020 14:35:5	304610	-865206	1286	194	194	195	2877	751	917	-1	121	3	0	0	12	0	5136	10678	974	3824
06/18/2020 14:35:5	304569	-865215	1505	194	191	192	2812	757	919	-1	122	3	0	0	12	0	5274	10661	981	4083
06/18/2020 14:36:0	304529	-865224	1627	194	194	197	524	702	897	-1	13	3	0	0	12	0	4076	10647	739	1818
06/18/2020 14:36:0	304488	-865234	1584	192	201	204	-522	622	864	-153	32	3	0	0	12	0	2938	10635	####	4278
06/18/2020 14:36:1	304444	-865239	1574	183	202	206	67	536	830	-227	53	3	0	0	12	0	2038	10627	####	4490
06/18/2020 14:36:1	304400	-865236	1601	174	200	203	365	448	793	-227	53	3	0	0	12	0	1295	10620	####	4013
06/18/2020 14:36:2	304359	-865225	1627	166	195	198	332	335	728	-219	57	3	0	0	12	0	688	10616	####	4503
06/18/2020 14:36:2	304320	-865210	1657	162	188	192	407	278	654	-50	58	3	0	0	12	0	688	10612	####	4644
06/18/2020 14:36:3	304283	-865193	1685	160	181	184	358	254	607	-36	64	3	0	0	11	0	688	10609	995	5376
06/18/2020 14:36:3	304248	-865177	1709	159	173	177	297	256	616	-36	72	3	0	0	11	0	688	10607	998	6245

Sheet1 simFDR724

Figure 37. Simulator data output – Cluj-Napoca simulator

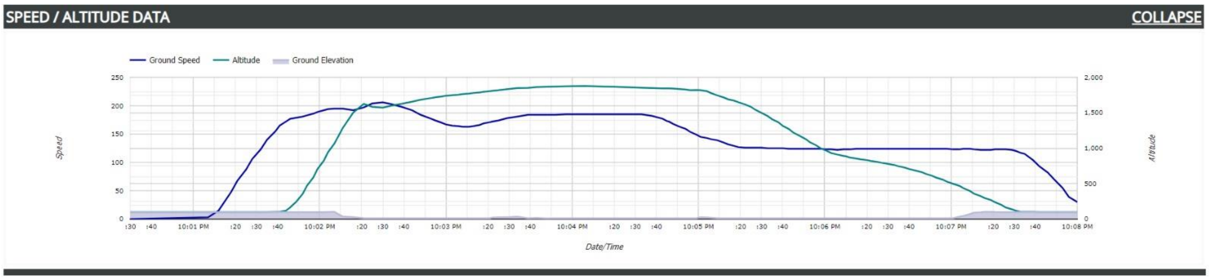


Figure 38. Simulator data output – Cluj-Napoca simulator

Appendix 3 – Simulation: initial position, plotting the flight path, and extracting the data

Initial position

The initial position was clearly defined, starting with crew number 4. The first three crews were used to test the simulation process. They were positioned at cruising altitude of FL350, flying westbound over the Austro-Hungarian border, South of Bratislava. Budapest was more than 80NM straight ahead, while Vienna and Bratislava will be within the 40NM range. I found that setting up this position in the simulator was imprecise in both the Wizz Air and the FlightX simulators, as none of the simulators shows the borders on the simulator map and there was no Latitude/Longitude position previously defined.

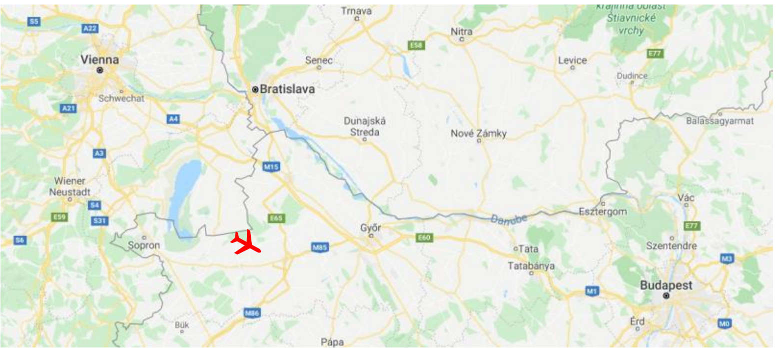


Figure 39. Simulation 1 to 3 approximate initial position - map view

Starting with crew number 4, the simulations were done using an identical setup and standardized positioning method. The positioning was done by performing a take-off from VIE RWY11, maintaining runway heading until reaching 40NM from VIE RWY29 ILS. The simulation continued in 'position freeze' until the climb to FL350 was completed. This became the new starting position for the research, a more precise and more straightforward setup. The initial position change does not impact the research results, as the first three simulations were used for testing purposes and do not count towards the simulation research results.

Figure 40. Crew 5 to 12: initial position

Simulation data from the Wizz Air certified simulator in Budapest

The Wizz Air simulator in Budapest generated a complete flight path profile (plan view), a zoomed flight path profile (plan view), and a short final ILS vertical profile. The path profiles were imported into the Google Earth Pro online platform as an overlay picture. The accuracy of the distance was ensured using the range circle printed on the simulator-generated profiles overlaid on a manually created range circle created in Google Earth. A more precise location was determined by overlaying the simulator generated airport diagram on the Google Earth airport diagram.

Figure 41. Google Earth PRO manual reconstruction of path profile - Budapest simulator

The distance information was retrieved from manually recreating the aeroplane path over the overlaid simulator-generated profiles in Google Earth.

The altitude, speed, and configuration information were inferred from the video recordings and manually plotted on the Google Earth map.

Simulation data from the FlightX non-certified simulator in Cluj-Napoca

The FlightX simulator in Cluj-Napoca uses simFDR as a software tool that generates a complex set of data, exportable into an Excel file as follows:

	Date/Time	Latitude	Longitude	Altitude	Heading	Air Speed	Ground Speed	Vertical Speed	N1	N2	Bank	Pitch	Flaps	WindSpeed	WindHdg	Temperature	Pressure	FuelFlow	Fuel	Gs	AOA	NAV	HDG	APR	ALT	AT	FrameRate	WARN
2	11/20/2020 12:45:3	481227	165337	610	106	0	0	0	194	600	0	-3	10	0	0	13	0	3869	10982	1000	-412						62	
3	11/20/2020 12:45:5	481227	165337	610	106	3	3	0	766	835	0	-2	10	0	0	13	0	16803	10978	1000	-249						57	
4	11/20/2020 12:45:5	481225	165342	610	111	25	25	0	899	897	1	-2	10	0	0	13	0	23367	10976	1000	-193						66	
5	11/20/2020 12:46:0	481221	165355	610	111	50	51	0	920	910	0	-2	10	0	0	13	0	24758	10975	1000	-179						65	
6	11/20/2020 12:46:0	481217	165368	610	111	67	68	0	925	915	0	-2	10	0	0	13	0	25258	10982	1000	-174						67	
7	11/20/2020 12:46:0	481211	165385	610	111	84	85	0	928	917	0	-2	10	0	0	13	0	25568	10975	1000	-171						52	
8	11/20/2020 12:46:1	481205	165406	610	111	101	102	0	928	918	0	-2	10	0	0	13	0	25776	10982	1000	-174						67	
9	11/20/2020 12:46:1	481197	165431	610	111	118	118	0	928	919	0	-2	10	0	0	13	0	25998	10975	1000	-181						48	
10	11/20/2020 12:46:1	481188	165459	611	111	134	134	0	928	920	0	-2	10	0	0	13	0	26238	10982	1002	-196						54	
11	11/20/2020 12:46:2	481177	165491	612	111	150	150	24	928	921	0	42	10	0	0	13	0	26110	10975	968	4088						61	
12	11/20/2020 12:46:2	481168	165521	612	111	163	164	10	929	923	0	53	10	0	0	13	0	25402	10975	1008	5206						54	
13	11/20/2020 12:46:2	481159	165548	618	111	174	174	183	929	923	0	49	10	0	0	13	0	24840	10975	1000	4105						48	
14	11/20/2020 12:46:3	481149	165577	619	111	185	185	-96	928	924	0	21	10	0	0	13	0	24204	10982	942	2966						54	
15	11/20/2020 12:46:3	481140	165607	621	111	195	195	235	927	924	1	51	10	0	0	13	0	23626	10976	1138	3381						47	
16	11/20/2020 12:46:3	481129	165639	650	111	205	204	607	927	924	1	38	9	0	0	13	0	23548	10982	930	2218						52	
17	11/20/2020 12:46:3	481118	165673	669	111	215	214	435	925	924	1	35	4	0	0	13	0	23614	10976	843	2610						56	
18	11/20/2020 12:46:4	481107	165708	674	111	226	225	95	924	924	1	25		0	0	13	0	23696	10982	758	2711						57	
19	11/20/2020 12:46:4	481096	165743	669	111	237	236	-36	922	925	1	30		0	0	13	0	23786	10976	934	3033						55	
20	11/20/2020 12:46:4	481083	165782	668	111	248	247	-11	921	925	1	63		0	0	13	0	23878	10982	1470	5566						52	
21	11/20/2020 12:46:4	481070	165822	768	111	254	250	2868	920	924	4	136		0	0	13	0	23872	10976	1365	4584						48	
22	11/20/2020 12:46:5	481057	165862	983	111	254	246	5303	919	924	0	193		0	0	13	0	23718	10982	1499	4985						48	
23	11/20/2020 12:46:5	481044	165901	1290	111	251	240	7225	920	924	-1	197		0	0	12	0	23468	10982	1003	2534						54	

Figure 42. simFDR data output - Cluj-Napoca simulator

The latitude/longitude/altitude/speed values were then imported in Google Earth Pro. The flight path, altitude, speed, and configuration details can thus be retrieved with a higher degree of accuracy. The final simulation profiles present the data relevant to the intended measurements.

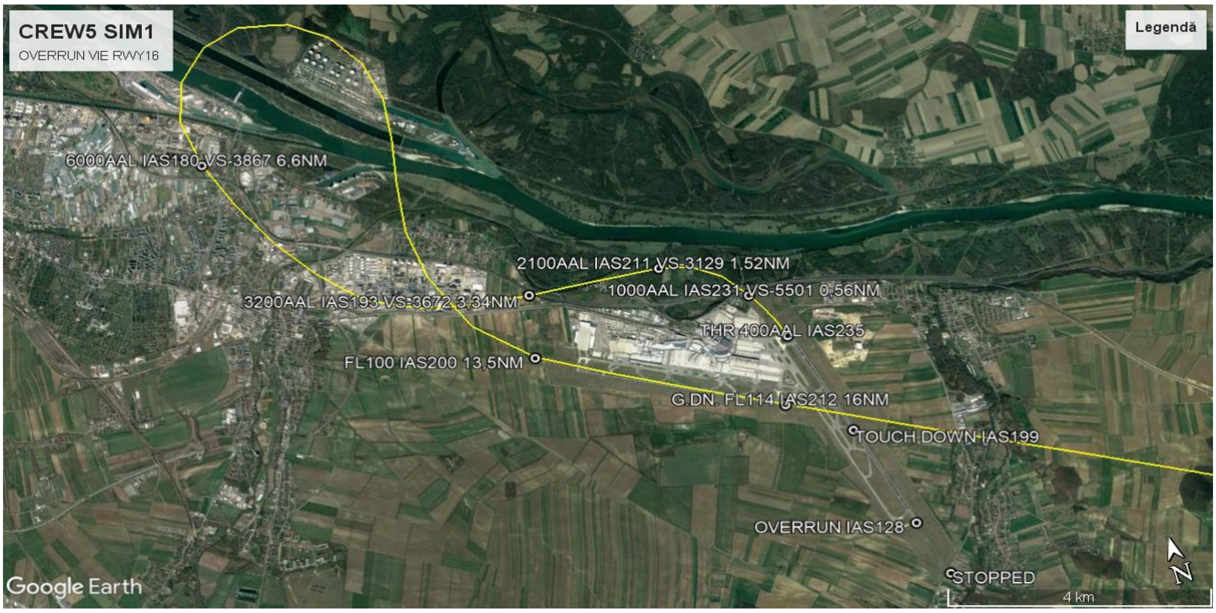


Figure 43. Google Earth PRO final simulation profile - both simulators

Studying the flight profile required a definition of a reference profile, and this was done using the Airbus QRH and heuristic reference profiles. Aspects like the altitude, distance to the runway threshold, speed, altitude, and speed at the threshold were noted. The performance of the crew was tabulated for the first and third simulation. The same parameters were observed to determine the variation around the reference profiles. The delta distance to the threshold, speed (per each relevant flight level) and speed and altitude at the threshold were recorded. Finally, it was noted whether or not the landing was successful.

Appendix 4 – Questionnaires: calibration and data extraction

China Lake Situational Awareness Rating Scale

SA Scale Value	Content
VERY GOOD 1	Full knowledge of a/c energy state/tactical environment/mission Full ability to anticipate or accommodate trends
GOOD 2	Full knowledge of a/c energy state/tactical environment/mission Partial ability to anticipate or accommodate trends No task shedding
ADEQUATE 3	Full knowledge of a/c energy state/tactical environment/mission Saturated ability to anticipate or accommodate trends Some shedding of minor tasks
POOR 4	Fair knowledge of a/c energy state/tactical environment/mission Saturated ability to anticipate or accommodate trends Shedding of all minor tasks as well as many not essential to flight safety/mission effectiveness
VERY POOR 5	Minimal knowledge of a/c energy state/tactical environment/mission Oversaturated ability to anticipate or accommodate trends Shedding of all tasks not absolutely essential to flight safety/mission effectiveness

Figure 44. China Lake Situational Awareness Rating Scale (Gawron, 2008, p.239)

The original form presented in figure 43 has been decomposed into its three sub-elements and re-worded for a better understanding:

1. knowledge of a/c energy state/environment/gliding distance
2. ability to anticipate or accommodate trends
3. shedding of tasks

The information has been recomposed in a tick-the-box tabulated form, which the pilots used to rate their SA perception at FL300, FL200, FL100 and 6000ft.

	Knowledge of a/c energy state, environment, gliding distance			Ability to anticipate or accommodate trends				Shedding of tasks			
	minimal	partial	full	over saturated	saturated	partial/ fair	full	All tasks not absolutely essential to flight safety	All minor tasks as well as many not essential to flight safety	Some minor tasks	No task shedding
FL300			X				X			X	
FL200			X				X		X		
FL100		X		X				X			
6000ft	X				X			X			

Figure 45. SA rating form

Bedford Workload Scale

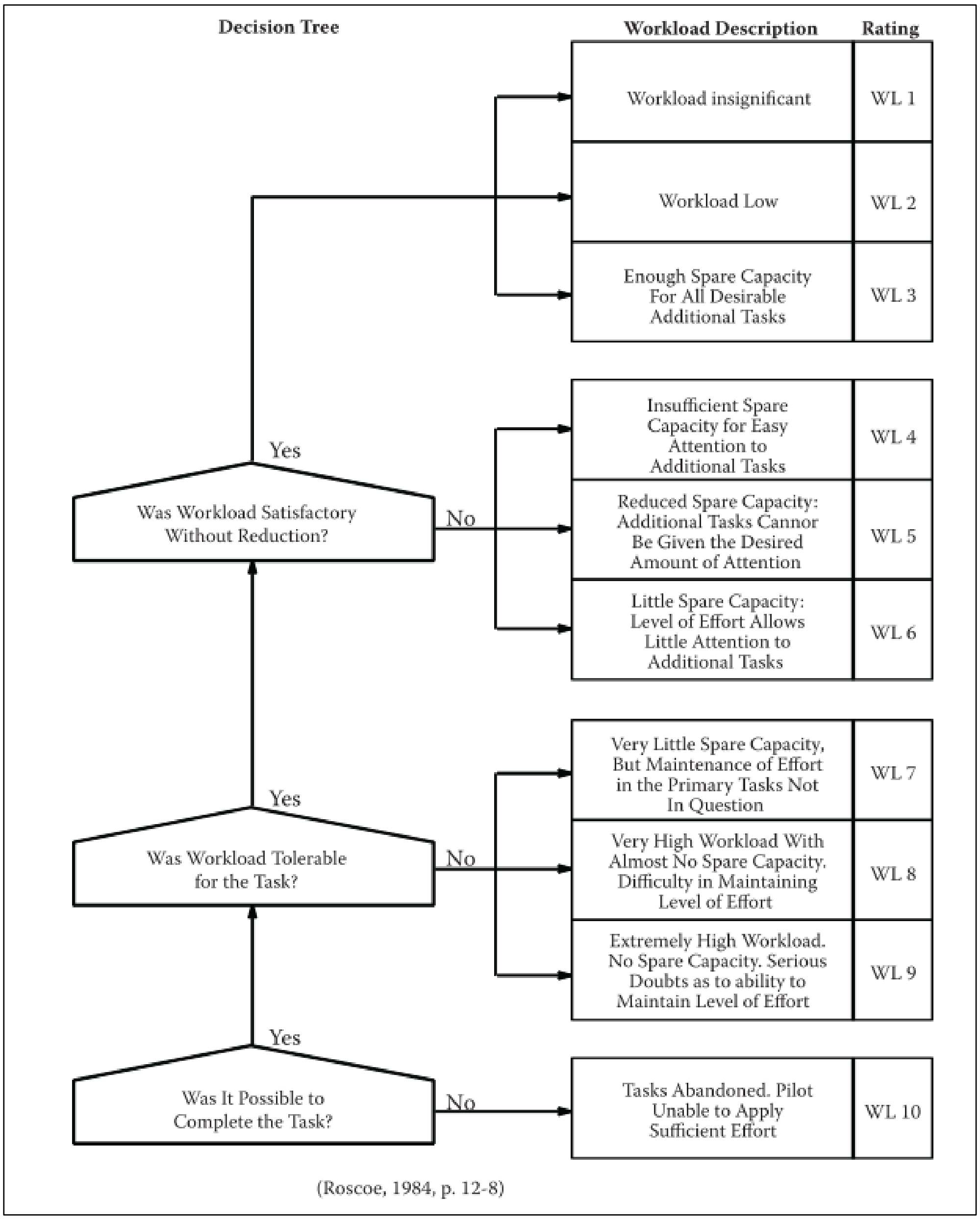


Figure 46. Bedford Workload Scale (Roscoe, 1984, p12-8, as cited by Gawron, 2008, p.161)

This rating scale has been used without any text modification.

Cooper-Harper Rating Scale

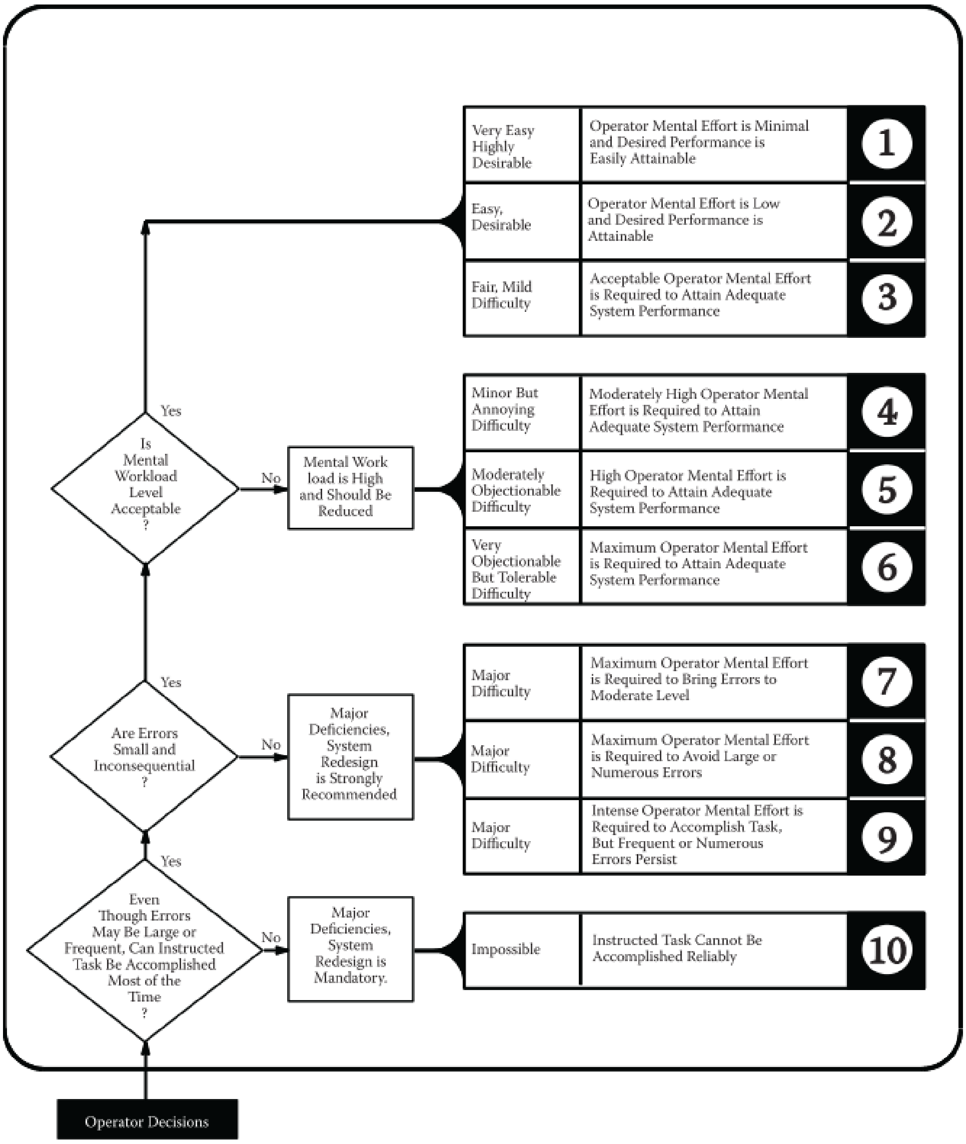


Figure 47. Modified Cooper-Harper Rating Scale (Gawron, 2008, p.168)

This rating scale has been re-worded for better understanding and presented as follows:

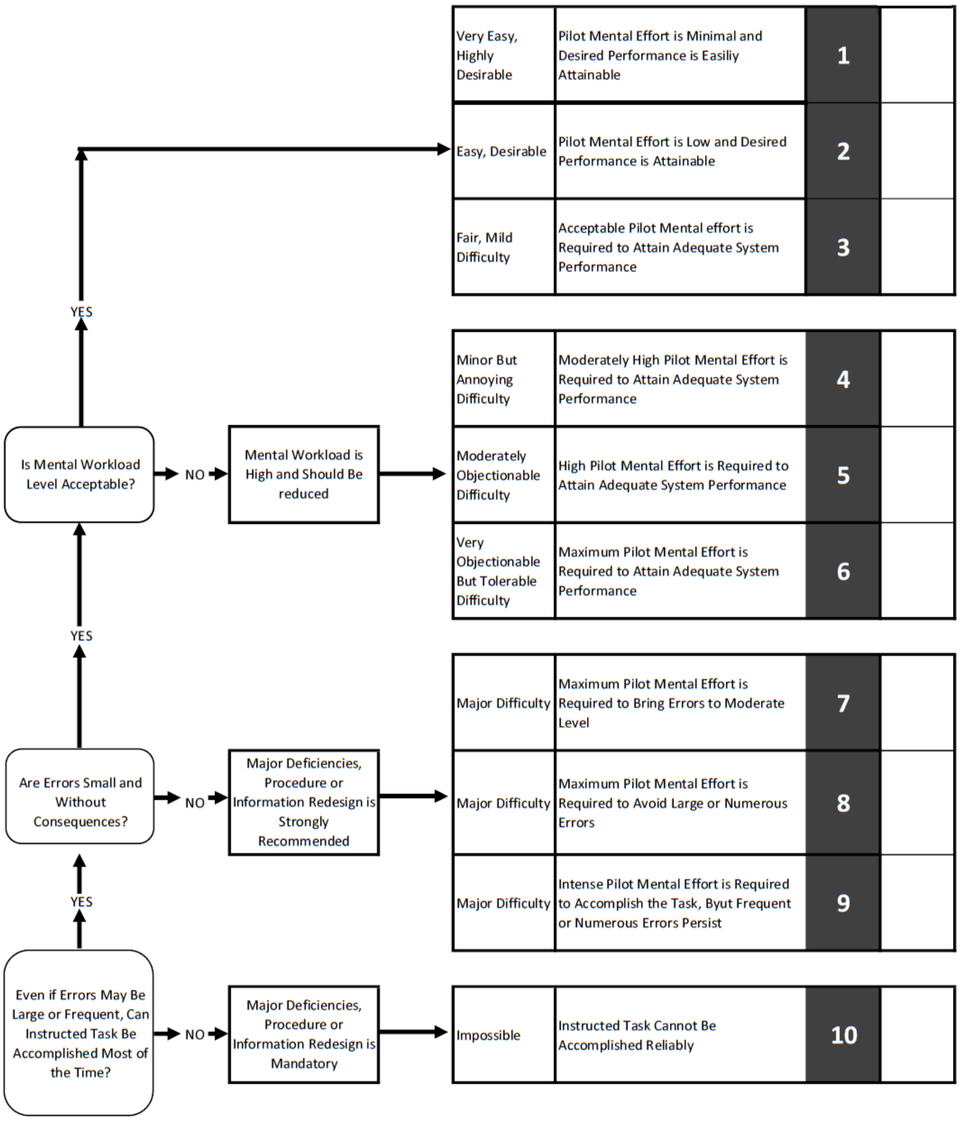


Figure 48. Reworded Modified Cooper-Harper Rating Scale (Gawron, 2008, p.168)

Crews number 1, 2, and 3 have filled out the questionnaire rating scales on paper. Starting with crew number 4, all the questionnaires have been moved online, using the www.surveymonkey.com online survey platform. The pilots were able to access this platform on their mobile phones after the first and third simulations. The results were exported in PDF format and then coded in a separate Excel file.

For the China Lake Situational Awareness Rating Scale, a weighted Situational Awareness (SA) average has been made for each relevant Flight Level (300, 200, 100, 60). This showed the mean Situational Awareness level as perceived by the crew when considering the three criteria being evaluated: knowledge of a/c energy state/environment/gliding distance, ability to anticipate or accommodate trends, and shedding of tasks. In the weighted average, the values correspond to the original SA Scale Values, and the weights are the number of occurrences for each value. (i.e., for an SA of 1 at A/C ES/ENV/GD, 2 at ability to accommodate and anticipate trends and 3 at shedding of tasks, each one would be taken into consideration once within the weighted average: (1 * 1 + 2 * 1 + 3 * 1) / (1 + 1 + 1) = 6 / 3 = 2).

The same rationale applies to determining the SA level for CM1 within SIM 2. Then, to determine whether the heuristics made any improvements to the level of SA for CM1 or not, a difference between the two SA levels was made. A positive delta indicates an improvement, while a negative delta indicates otherwise. The actual value of the delta reflects the jump along the SA Scale: a delta of 2 may indicate a jump from “Adequate” to “Very good” or from “Poor” to “Good”, for example.

Next, CM 2 must be taken into consideration as well, and so the same rationale will be applied to him, thus resulting in a delta SA for CM2 between SIM 1 and SIM 2.

In order to determine the improvement of the crew as a whole in the matter of SA, an average per simulation has been made between the crew members (i.e., if CM1 rates his SA at 3 and CM2 rates his SA at 2, then the crew average will be 2.5), resulting in two sets of SA's for every relevant flight level. Finally, to observe the difference in performance between the two simulations on a crew basis, a delta must be made between the two sets of SA's. Therefore, the result is a crew delta SA for every relevant flight level results. As before, a positive delta indicates an improvement, while a negative delta indicates otherwise.

The crew members were asked to assess their perceived workload level using the Bedford Workload Scale, noting the workload level for each simulation. A delta between the perceived workload level per crew member between simulations was made and compared to observe any judgment heuristics impact. A positive value suggests improvement, while a negative value indicates otherwise. Then, to indicate a general crew improvement in workload management abilities, an average was made between the values obtained for CM1 and those obtained for CM2.

Similarly, studying crew decision-making abilities required using a modified Cooper-Harper Rating Scale. A delta between the perceived decision-making ability level per crew member between simulations was made. Then, to indicate a general crew improvement in decision-making, an average was made between the values obtained for CM1 and those obtained for CM2.

Appendix 5 – Simulation profiles data & questionnaires results

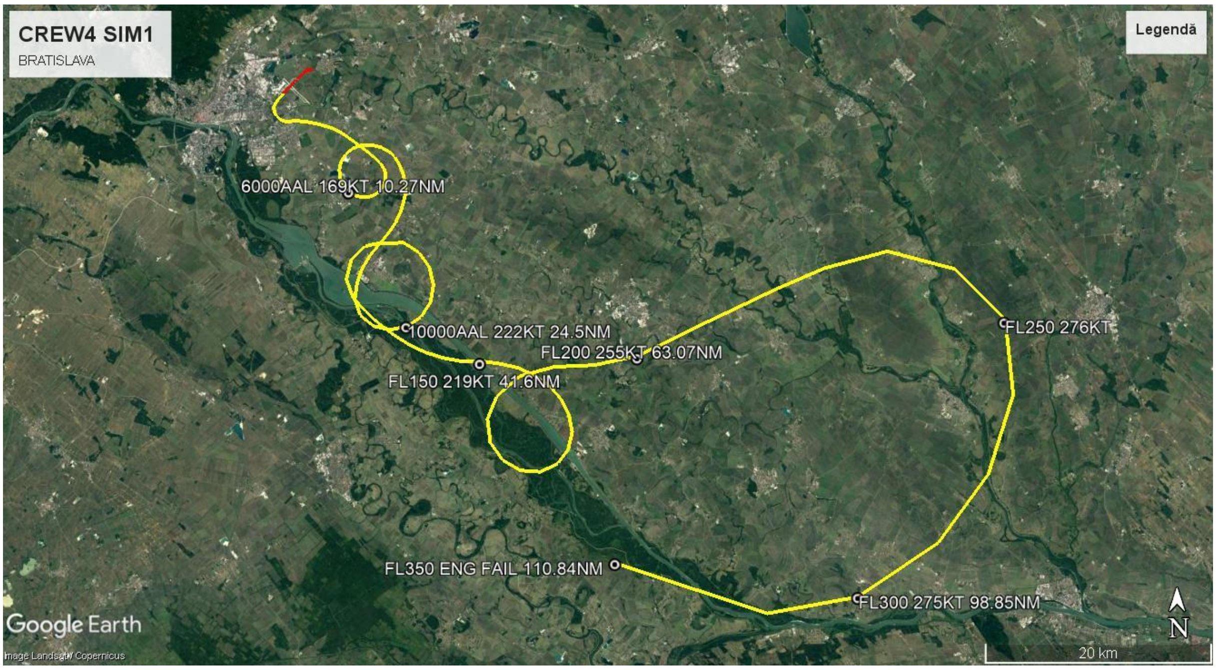


Figure 49. Crew 4 simulation 1 plan view

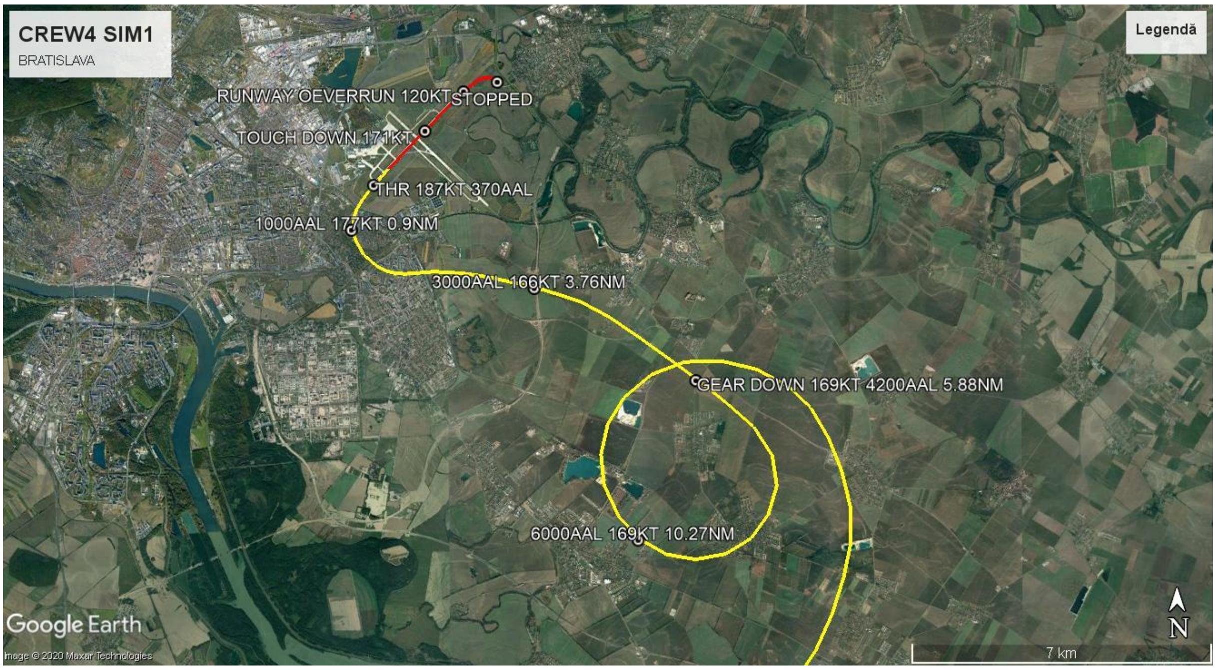


Figure 50. Crew 4 simulation 1 plan view (zoomed)

CREW 4 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		63.07	220	14.07	14
FL100		24.5	220	0.5	14
3000 ft		3.76	166	-1.24	0
ALT AT THR	370	0	187	THR IAS	21
LANDING	RUNWAY OVERRUN			THR ALT	320

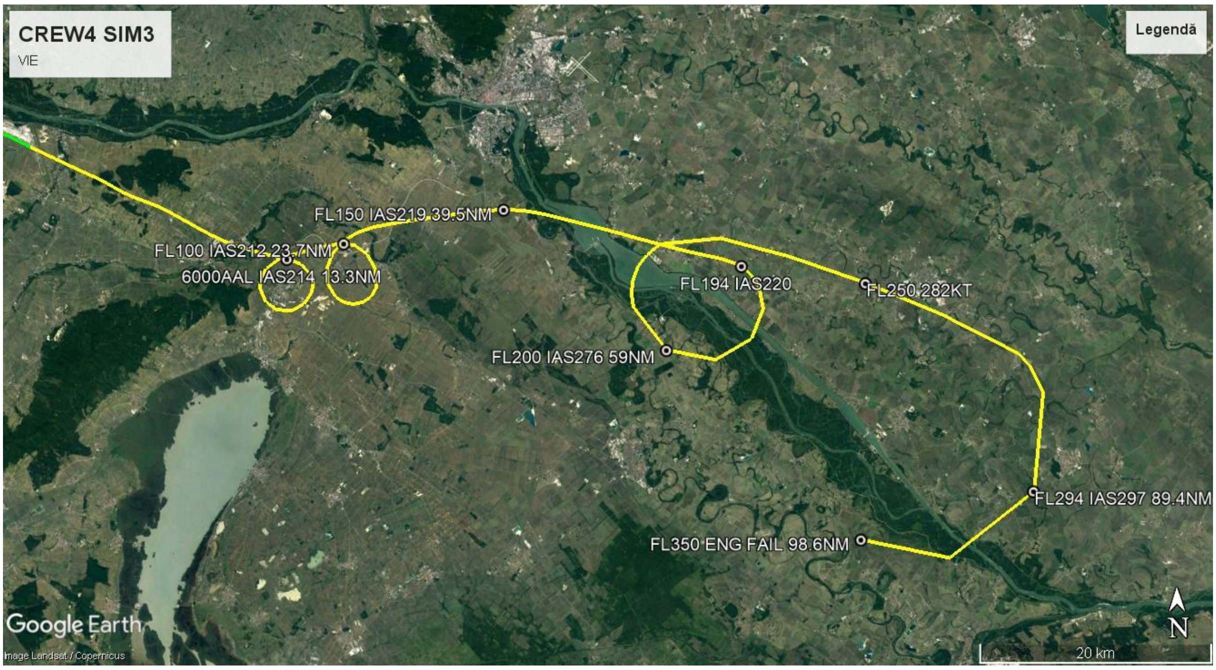


Figure 51. Crew 4 simulation 3 plan view

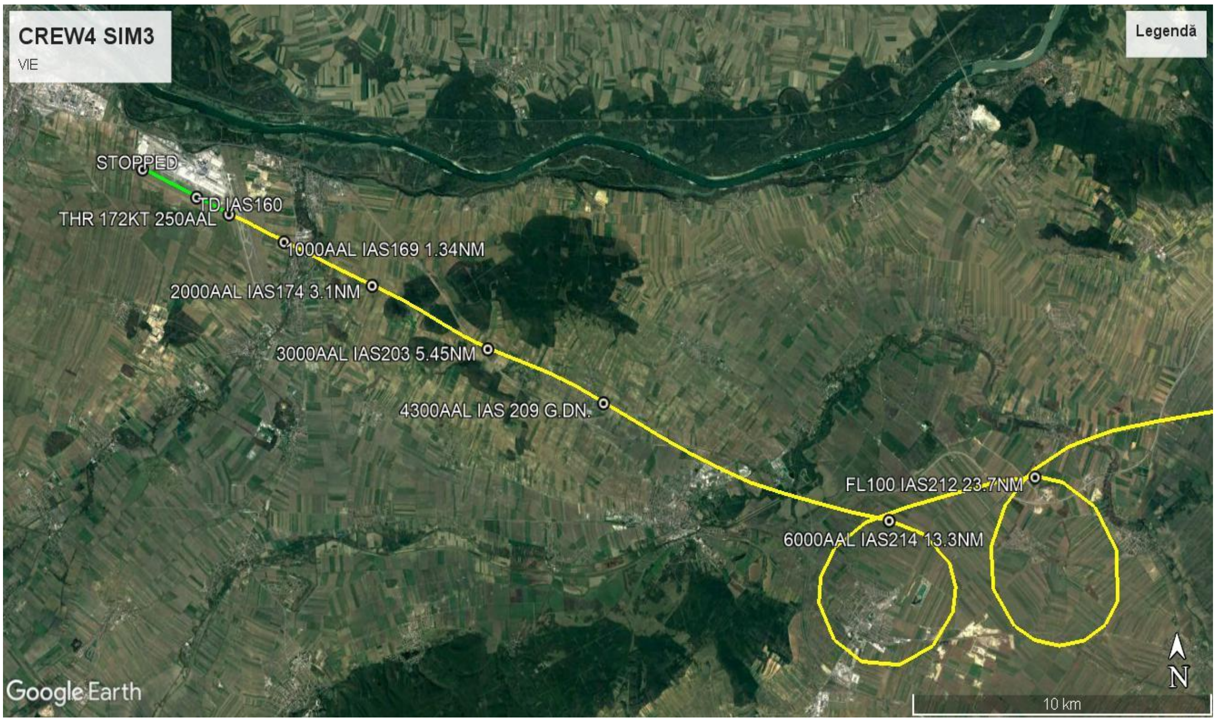


Figure 52. Crew 4 simulation 3 plan view (zoomed)

CREW 4 PROFILE SIM 3

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		59	276	19	70
FL100		23.7	212	3.7	6
3000 ft		5.45	203	-0.55	13
ALT AT THR	256	0	172	THR IAS	6
LANDING	SUCCESSFUL			THR ALT	206

CREW 4

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	3.5	FL300	2.4	FL300	1.1
FL200	3.75	FL200	2.4	FL200	1.35
FL100	4.666666667	FL100	2.2	FL100	2.466666667
6000 ft	3.2	6000 ft	1.6	6000 ft	1.6

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	3	FL300	3.5	FL300	-0.5
FL200	3	FL200	3	FL200	0
FL100	3.333333333	FL100	2.4	FL100	0.933333333
6000 ft	2.75	6000 ft	2.4	6000 ft	0.35

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	3.25	FL300	2.95	FL300	0.3
FL200	3.375	FL200	2.7	FL200	0.675
FL100	4	FL100	2.3	FL100	1.7
6000 ft	2.975	6000 ft	2	6000 ft	0.975

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	CREW WL Δ
10	3	7	7
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
10	3	7	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	CREW DM Δ
10	3	7	6
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
8	3	5	

Figure 53. Crew 5 simulation 1 plan view

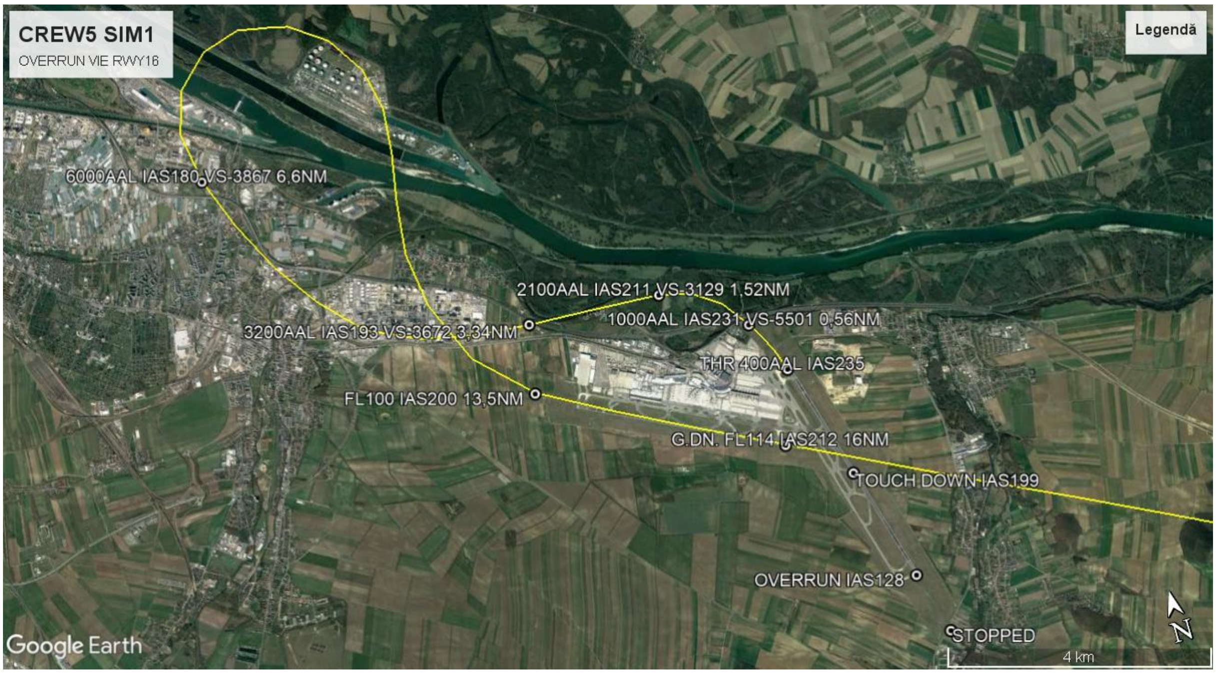


Figure 54. Crew 5 simulation 1 plan view (zoomed*)*

CREW 5 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		51.4	214	2.4	8
FL100		13.5	200	-10.5	-6
3000 ft		3.34	193	-1.66	27
ALT AT THR	400	0	235	THR IAS	69
LANDING	RWY OVERRUN			THR ALT	350

Figure 55. Crew 5 simulation 3 plan view

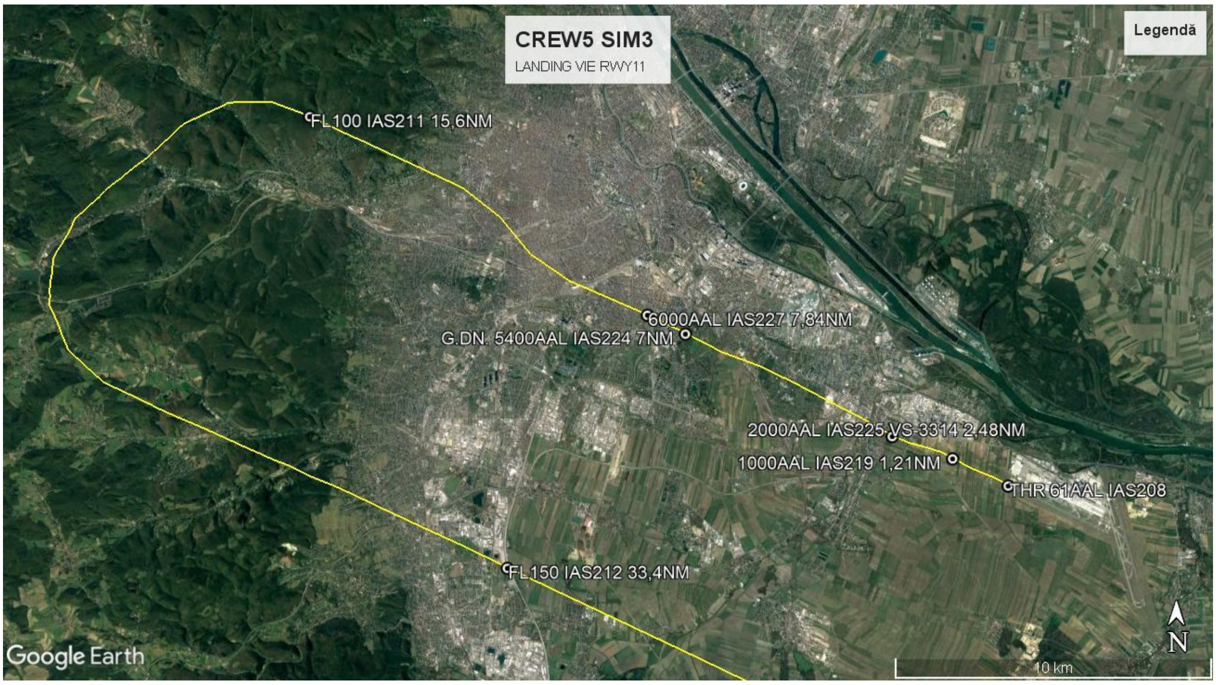


Figure 56. Crew 5 simulation 3 plan view (zoomed)

CREW 5 PROFILE SIM 3

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		56.2	212	16.2	6
FL100		15.6	211	-4.4	5
3000 ft		3.78	222	-2.22	32
ALT AT THR	61	0	208	THR IAS	42
LANDING	SUCCESSFUL			THR ALT	11

CREW 5

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	2.2	FL300	1.666666667	FL300	0.533333333
FL200	2.2	FL200	1.666666667	FL200	0.533333333
FL100	3.2	FL100	1.666666667	FL100	1.533333333
6000 ft	3.666666667	6000 ft	3.5	6000 ft	0.166666667

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	1.666666667	FL300	2.25	FL300	-0.583333333
FL200	3.5	FL200	3	FL200	0.5
FL100	3.6	FL100	2.2	FL100	1.4
6000 ft	2.5	6000 ft	2	6000 ft	0.5

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	1.933333333	FL300	1.958333333	FL300	-0.025
FL200	2.85	FL200	2.333333333	FL200	0.516666667
FL100	3.4	FL100	1.933333333	FL100	1.466666667
6000 ft	3.083333333	6000 ft	2.75	6000 ft	0.333333333

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	
10	6	4	CREW WL Δ
			4
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
7	3	4	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	
8	4	4	CREW DM Δ
			4.5
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
7	2	5	

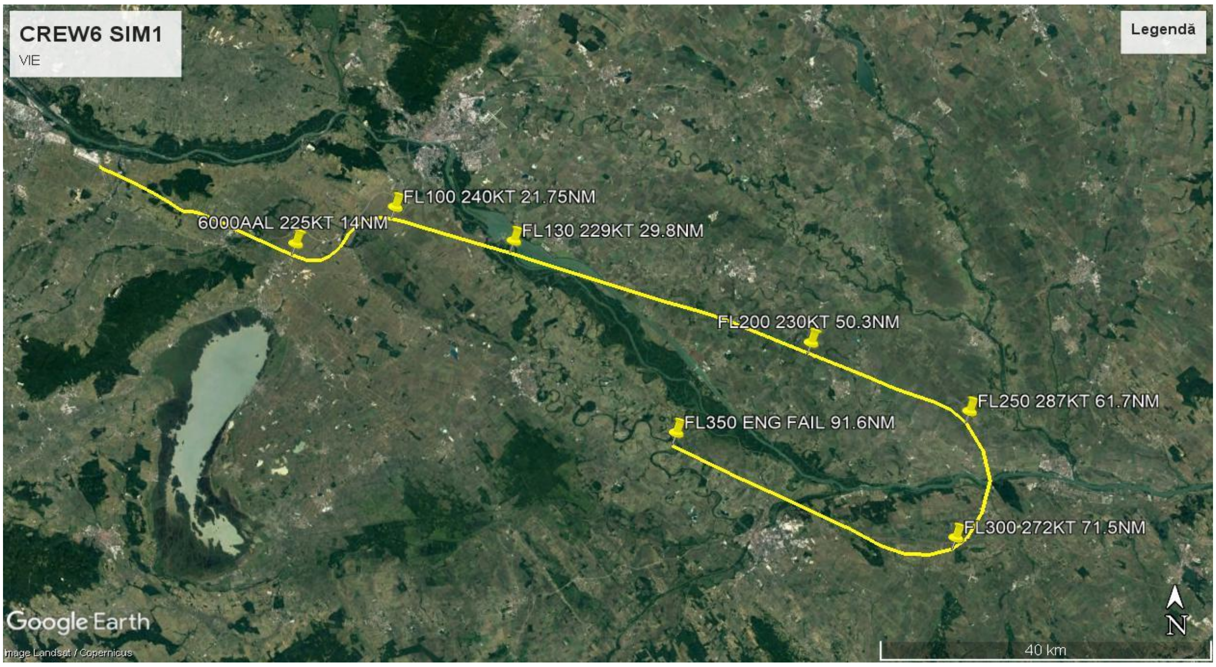


Figure 57. Crew 6 simulation 1 plan view

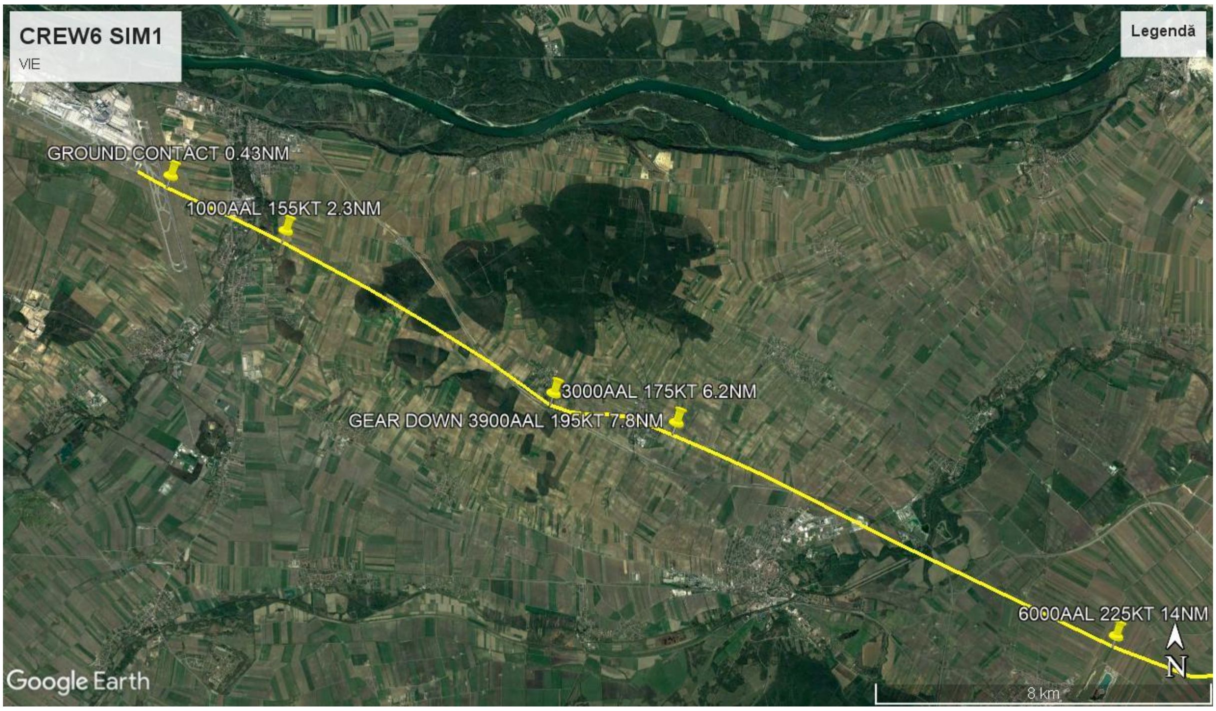


Figure 58. Crew 6 simulation 1 plan view (zoomed)

CREW 6 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		50.3	230	1.3	24
FL100		21.75	240	-2.25	34
3000 ft		6.2	175	1.2	9
ALT AT THR				THR IAS	
LANDING	Landing short of the runway			THR ALT	

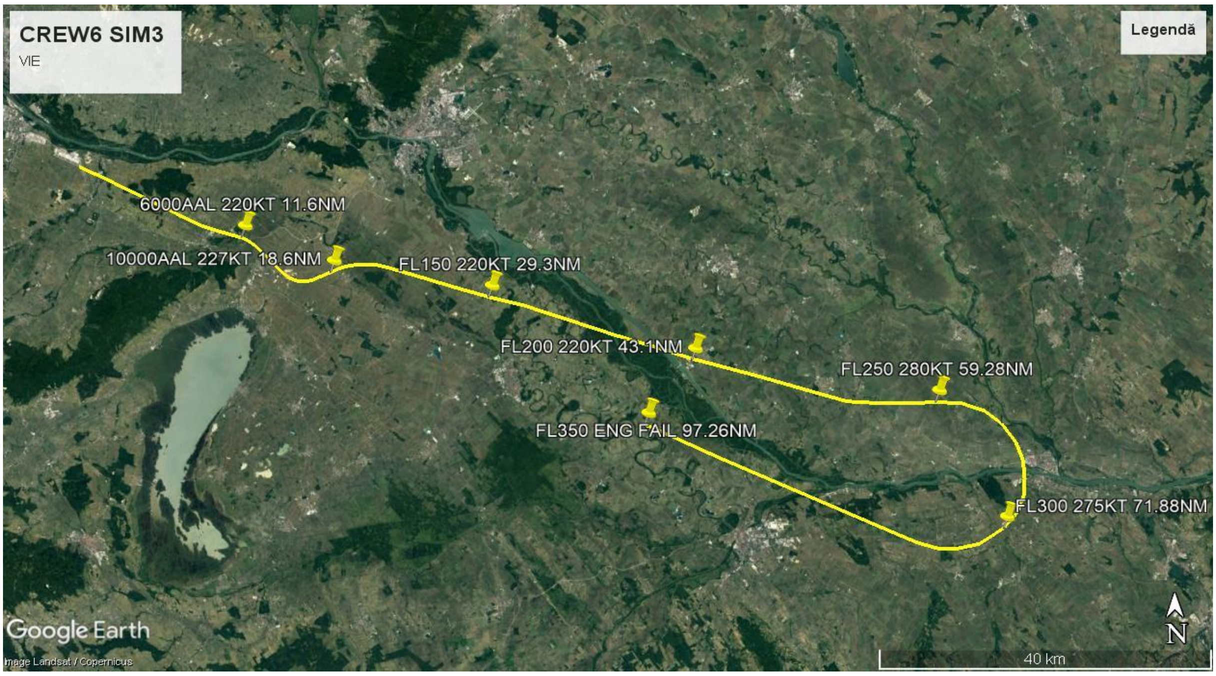


Figure 59. Crew 6 simulation 3 plan view

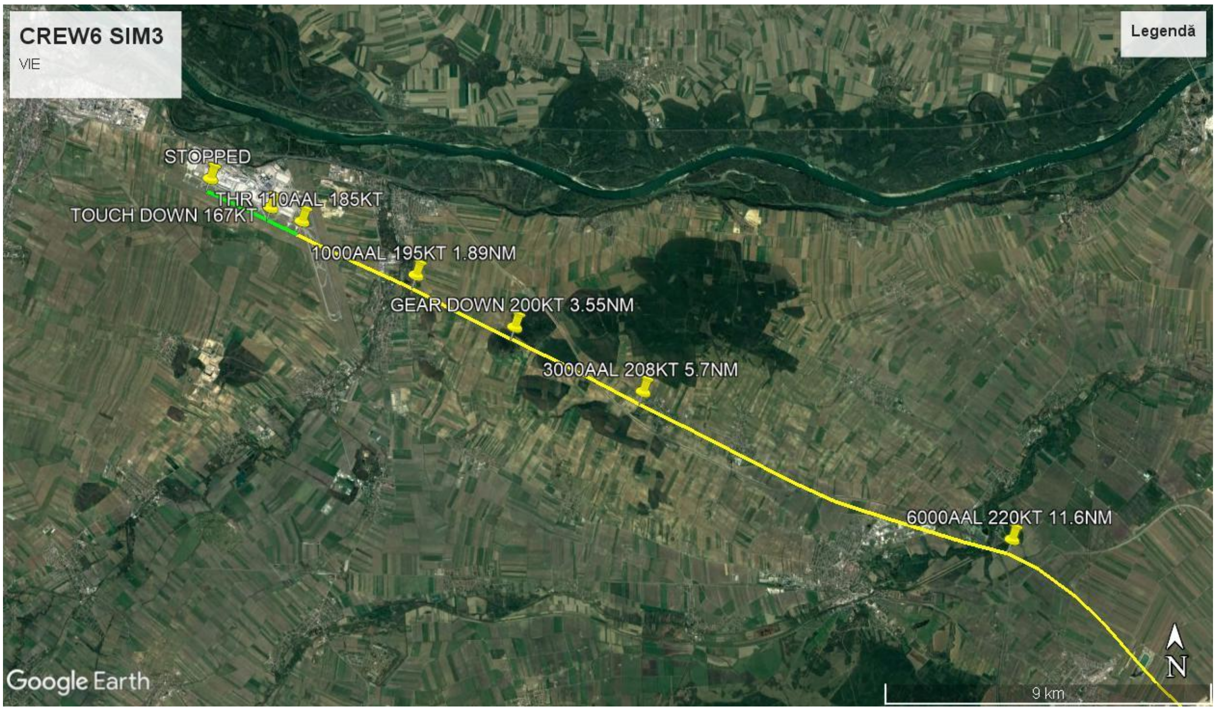


Figure 60. Crew 6 simulation 3 plan view (zoomed)

CREW 6 PROFILE SIM 3

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	29.3	220	-10.7	14
FL100	18.6	227	-1.4	21
3000 ft	5.7	208	-0.3	18
ALT AT THR	110	185	THR IAS	19
LANDING	SUCCESSFUL		THR ALT	60

CREW 6

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	3.75	FL300	2.6	FL300	1.15
FL200	3.75	FL200	2.4	FL200	1.35
FL100	3.5	FL100	2.4	FL100	1.1
6000 ft	4	6000 ft	2.75	6000 ft	1.25

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	2.2	FL300	1.666666667	FL300	0.533333333
FL200	4	FL200	1.666666667	FL200	2.333333333
FL100	4	FL100	2.2	FL100	1.8
6000 ft	5	6000 ft	4	6000 ft	1

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	2.975	FL300	2.133333333	FL300	0.841666667
FL200	3.875	FL200	2.033333333	FL200	1.841666667
FL100	3.75	FL100	2.3	FL100	1.45
6000 ft	4.5	6000 ft	3.375	6000 ft	1.125

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	CREW WL Δ
10	3	7	7
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
10	3	7	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	CREW DM Δ
10	3	7	7
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
10	3	7	

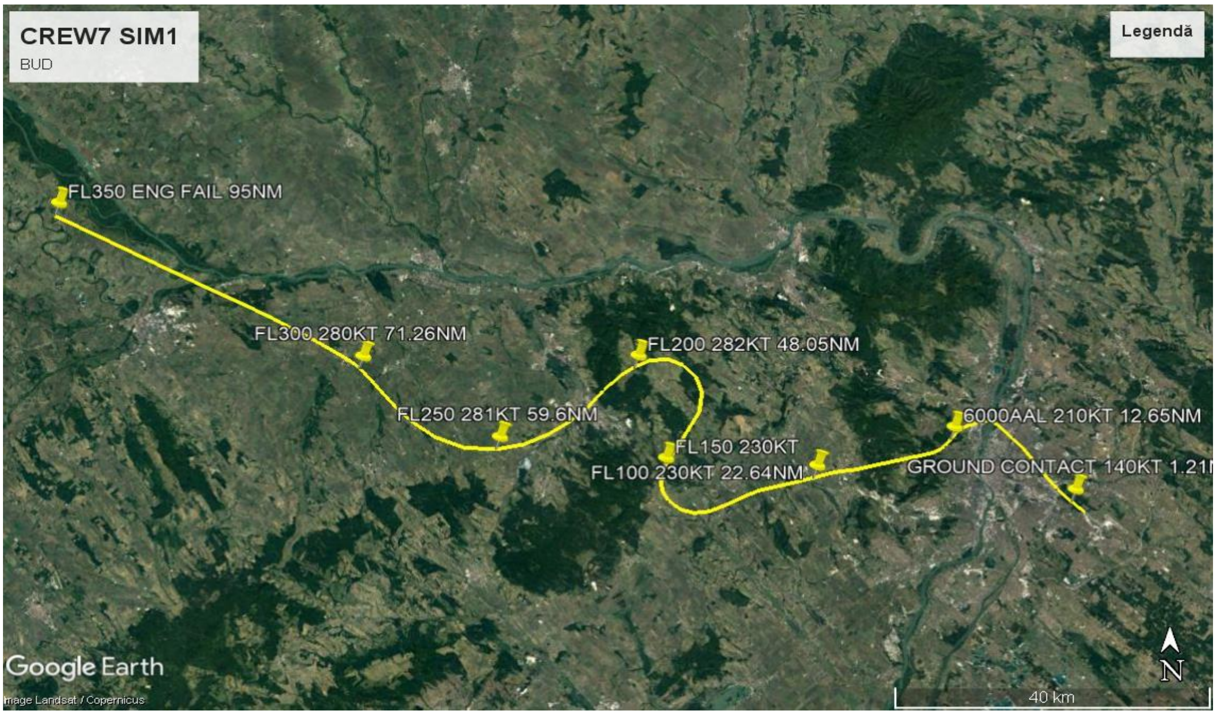


Figure 61. Crew 7 simulation 1 plan view

Figure 62. Crew 7 simulation 1 plan view (zoomed)

CREW 7 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		48.05	282	-0.95	76
FL100		22.64	230	-1.36	24
3000 ft		6.48	160	1.48	-6
ALT AT THR				THR IAS	
LANDING	Landing short of the runway			THR ALT	

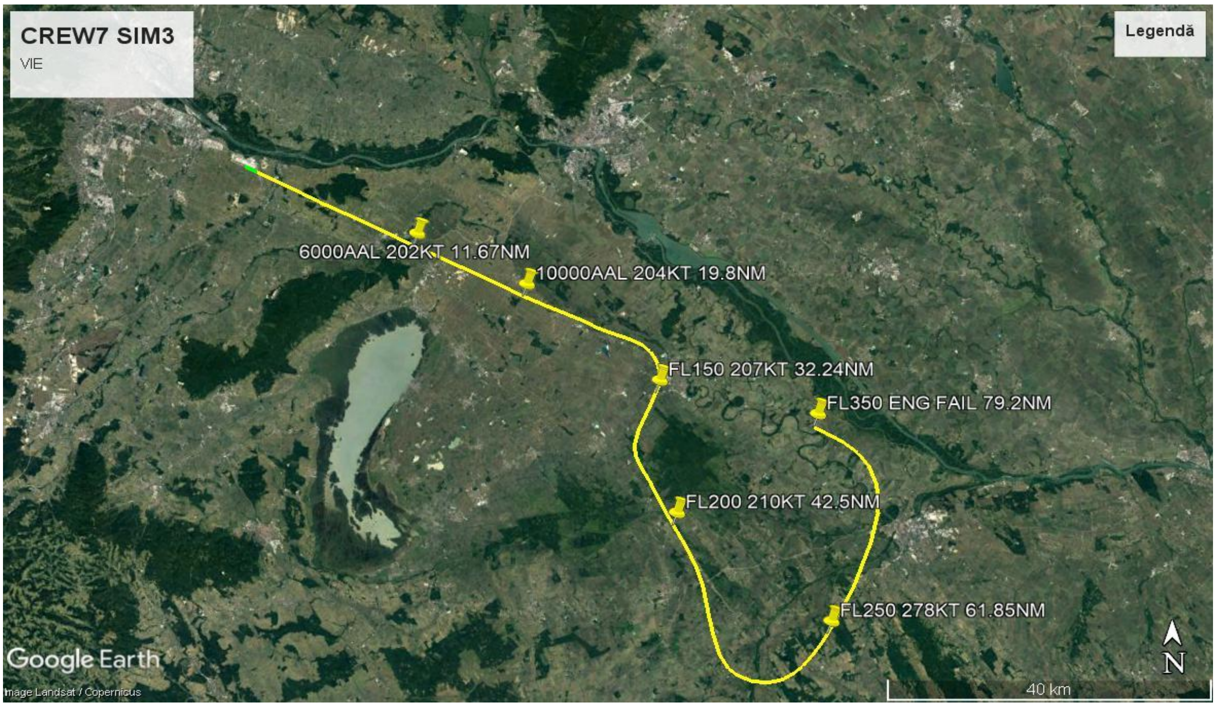


Figure 63. Crew 7 simulation 3 plan view

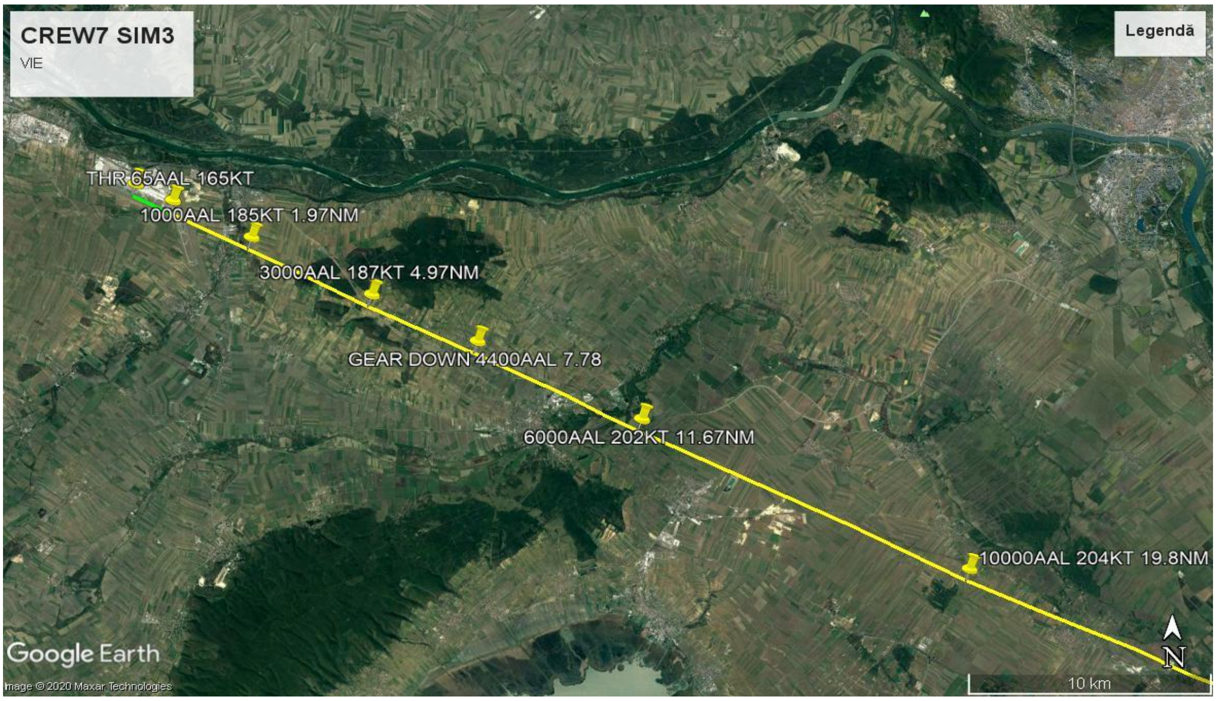


Figure 64. Crew 7 simulation 3 plan view (zoomed)

CREW 7 PROFILE SIM 3

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	42.5	210	2.5	4
FL100	19.8	204	-0.2	-2
3000 ft	4.97	187	-1.03	-3
ALT AT THR	65	165	THR IAS	-1
LANDING	SUCCESSFUL		THR ALT	15

CREW 7

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	2.4	FL300	2.2	FL300	0.2
FL200	2.5	FL200	2.2	FL200	0.3
FL100	3.75	FL100	2.166666667	FL100	1.583333333
6000 ft	4.333333333	6000 ft	3.5	6000 ft	0.833333333

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	2.4	FL300	2	FL300	0.4
FL200	2.4	FL200	2	FL200	0.4
FL100	3.333333333	FL100	2	FL100	1.333333333
6000 ft	4.5	6000 ft	2.25	6000 ft	2.25

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	2.4	FL300	2.1	FL300	0.3
FL200	2.45	FL200	2.1	FL200	0.35
FL100	3.541666667	FL100	2.083333333	FL100	1.458333333
6000 ft	4.416666667	6000 ft	2.875	6000 ft	1.541666667

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	CREW WL Δ
10	3	7	7
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
10	3	7	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	CREW DM Δ
10	2	8	6.5
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
10	5	5	

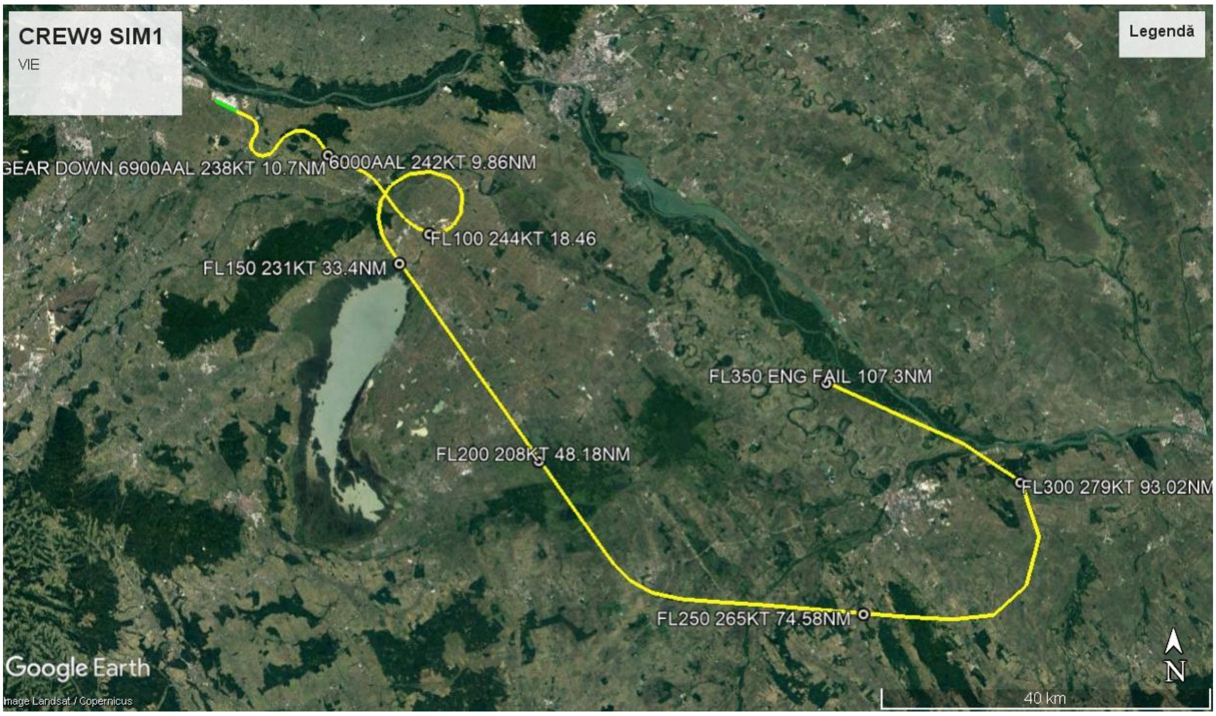


Figure 65. Crew 9 simulation 1 plan view

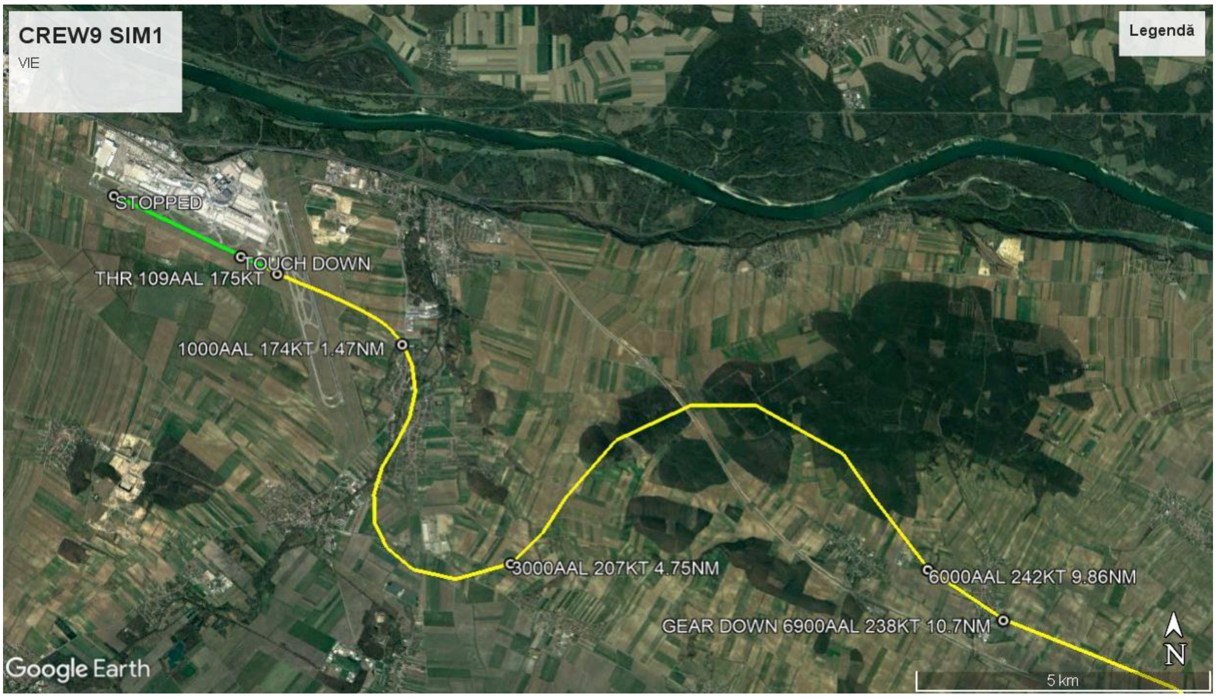


Figure 66. Crew 9 simulation 1 plan view (zoomed)

CREW 9 PROFILE SIM 1

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	48.18	208	-0.82	2
FL100	18.46	244	-5.54	38
3000 ft	4.75	207	-0.25	41
ALT AT THR	109	175	THR IAS	9
LANDING	SUCCESSFUL		THR ALT	59

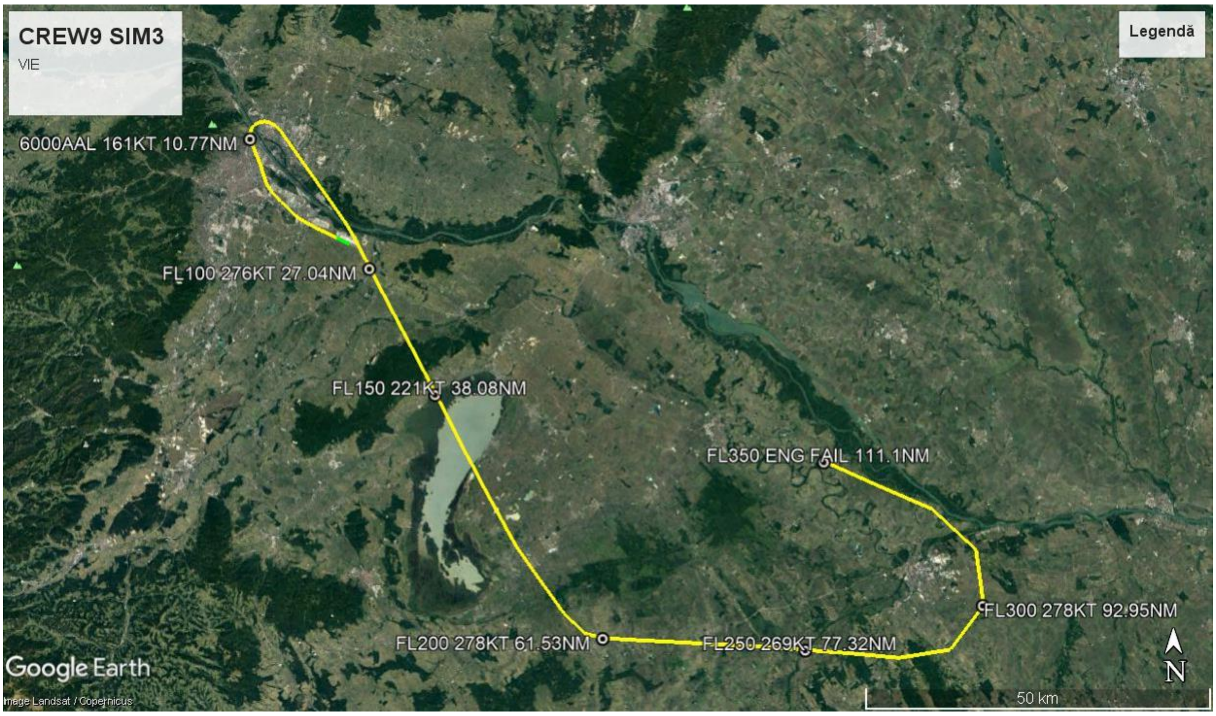


Figure 67. Crew 9 simulation 3 plan view

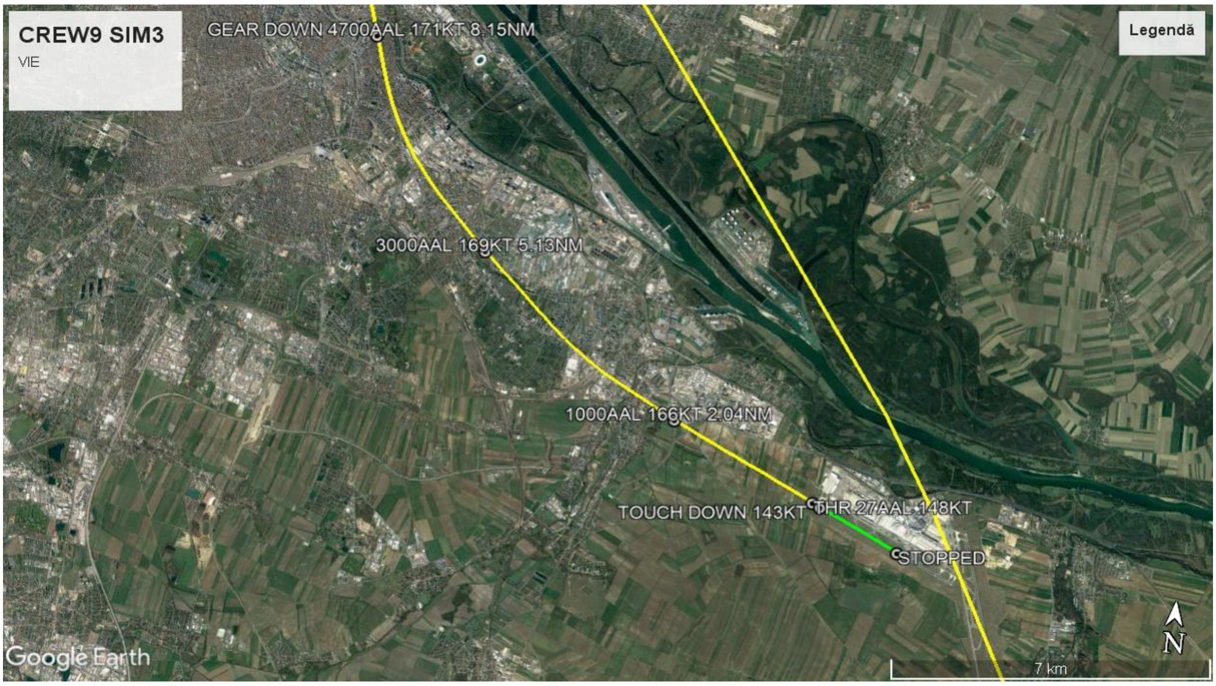


Figure 68. Crew 9 simulation 3 plan view (zoomed)

CREW 9 PROFILE SIM 3

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	61.53	278	21.53	72
FL100	27.04	276	7.04	70
3000 ft	5.13	169	-0.87	-21
ALT AT THR	27	148	THR IAS	-18
LANDING	SUCCESSFUL		THR ALT	-23

CREW 9

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	3	FL300	2	FL300	1
FL200	3.5	FL200	2	FL200	1.5
FL100	3.75	FL100	2	FL100	1.75
6000 ft	5	6000 ft	2.5	6000 ft	2.5

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	2.25	FL300	2	FL300	0.25
FL200	4.333333333	FL200	2	FL200	2.333333333
FL100	4.333333333	FL100	2	FL100	2.333333333
6000 ft	4.666666667	6000 ft	4	6000 ft	0.666666667

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	2.625	FL300	2	FL300	0.625
FL200	3.916666667	FL200	2	FL200	1.916666667
FL100	4.041666667	FL100	2	FL100	2.041666667
6000 ft	4.833333333	6000 ft	3.25	6000 ft	1.583333333

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	
6	3	3	CREW WL Δ
			2.5
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
5	3	2	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	
6	3	3	CREW DM Δ
			3
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
6	3	3	

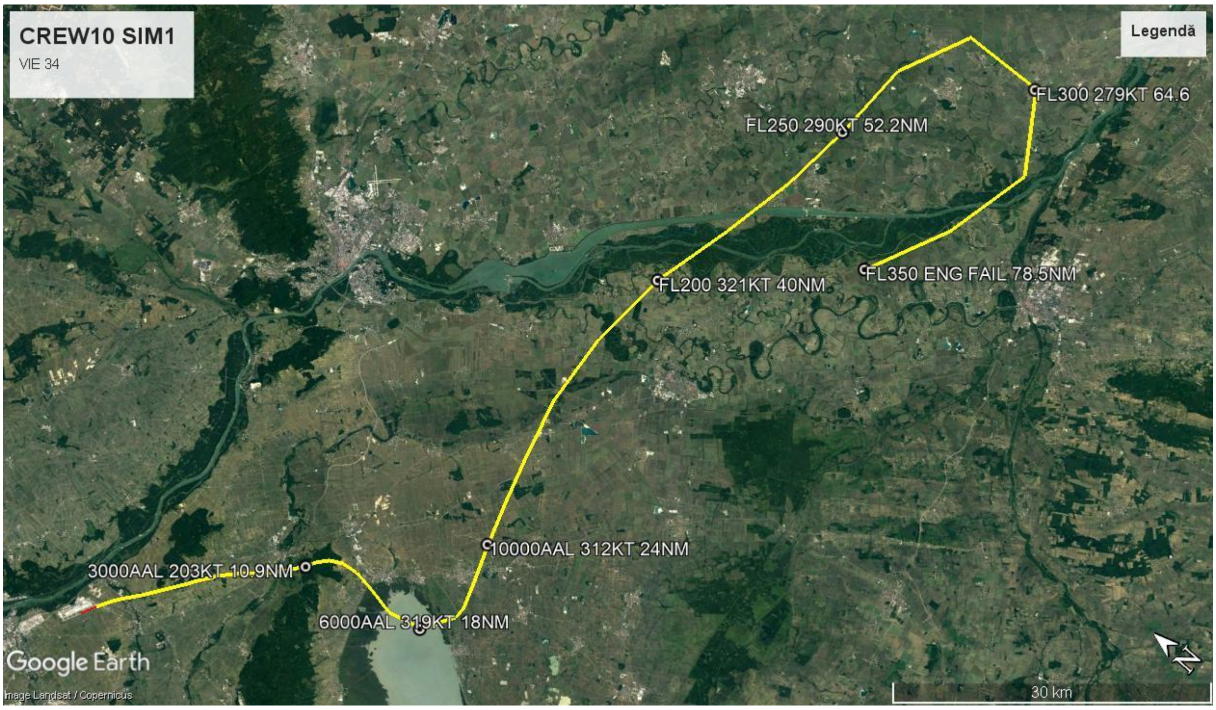


Figure 69. Crew 10 simulation 1 plan view

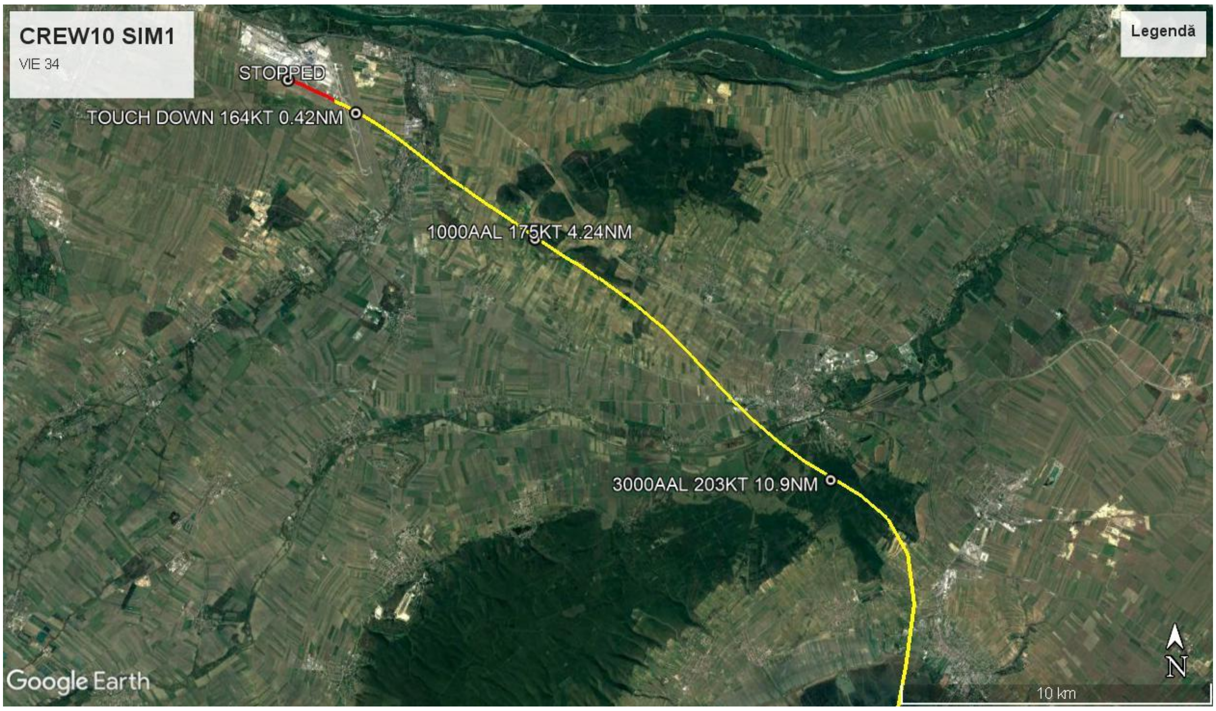


Figure 70. Crew 10 simulation 1 plan view (zoomed)

CREW 10 PROFILE SIM 1

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	40	321	-9	115
FL100	24	312	0	106
3000 ft	10.9	203	5.9	37
ALT AT THR	0		THR IAS	
LANDING	Landing short of the runway		THR ALT	

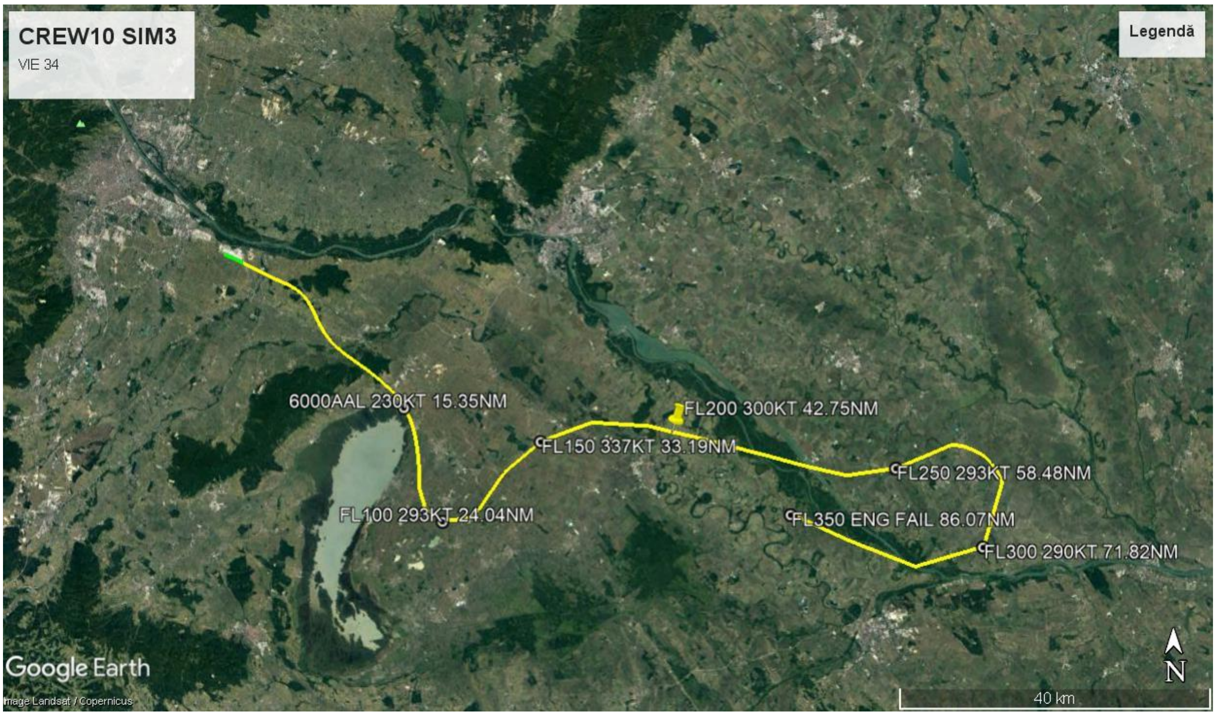


Figure 71. Crew 10 simulation 3 plan view

Figure 72. Crew 10 simulation 3 plan view (zoomed)

CREW 10 PROFILE SIM 3

FL/ALTITUDE	DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200	42.75	300	2.75	94
FL100	24.04	293	4.04	87
3000 ft	5.9	217	-0.1	27
ALT AT THR	117	178	THR IAS	12
LANDING	SUCCESSFUL		THR ALT	67

CREW 10

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	2.2	FL300	3	FL300	-0.8
FL200	4	FL200	2.2	FL200	1.8
FL100	4.666666667	FL100	2.2	FL100	2.466666667
6000 ft	4.666666667	6000 ft	2.25	6000 ft	2.416666667

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	4	FL300	2.2	FL300	1.8
FL200	4	FL200	2.2	FL200	1.8
FL100	4.666666667	FL100	2.2	FL100	2.466666667
6000 ft	4.666666667	6000 ft	2.25	6000 ft	2.416666667

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	3.1	FL300	2.6	FL300	0.5
FL200	4	FL200	2.2	FL200	1.8
FL100	4.666666667	FL100	2.2	FL100	2.466666667
6000 ft	4.666666667	6000 ft	2.25	6000 ft	2.416666667

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	CREW WL Δ
10	3	7	7
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
10	3	7	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	CREW DM Δ
10	4	6	6
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
10	4	6	

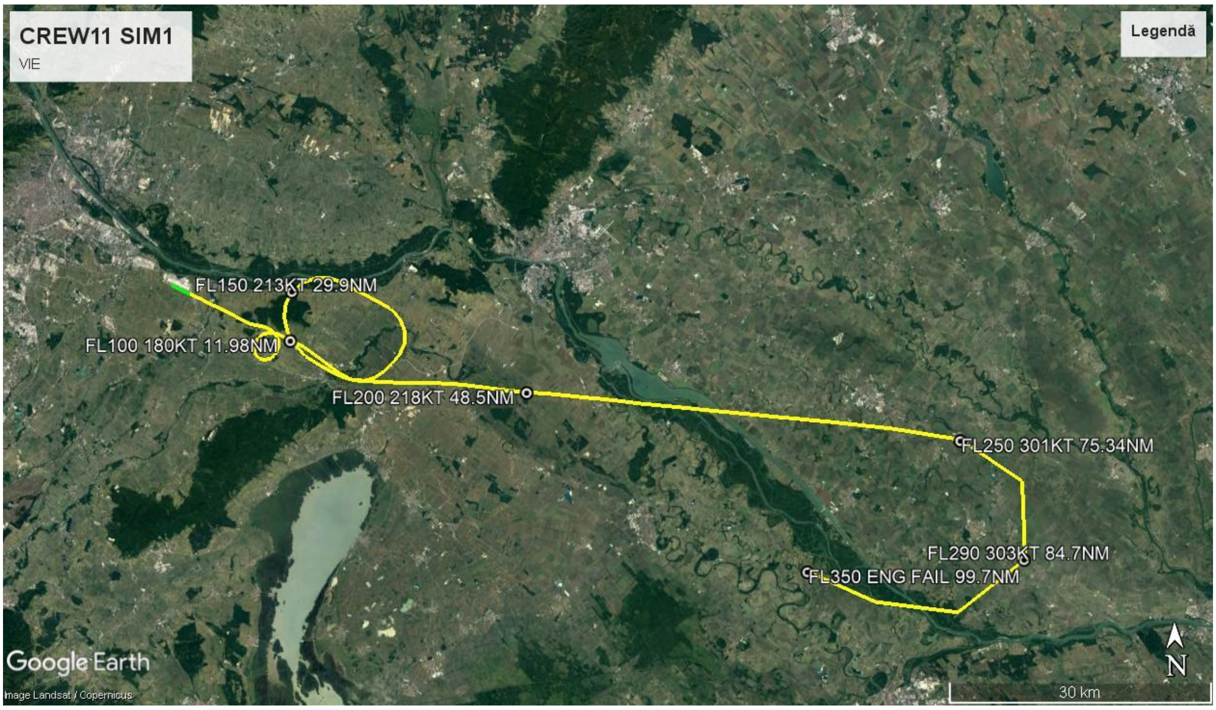


Figure 73. Crew 11 simulation 1 plan view

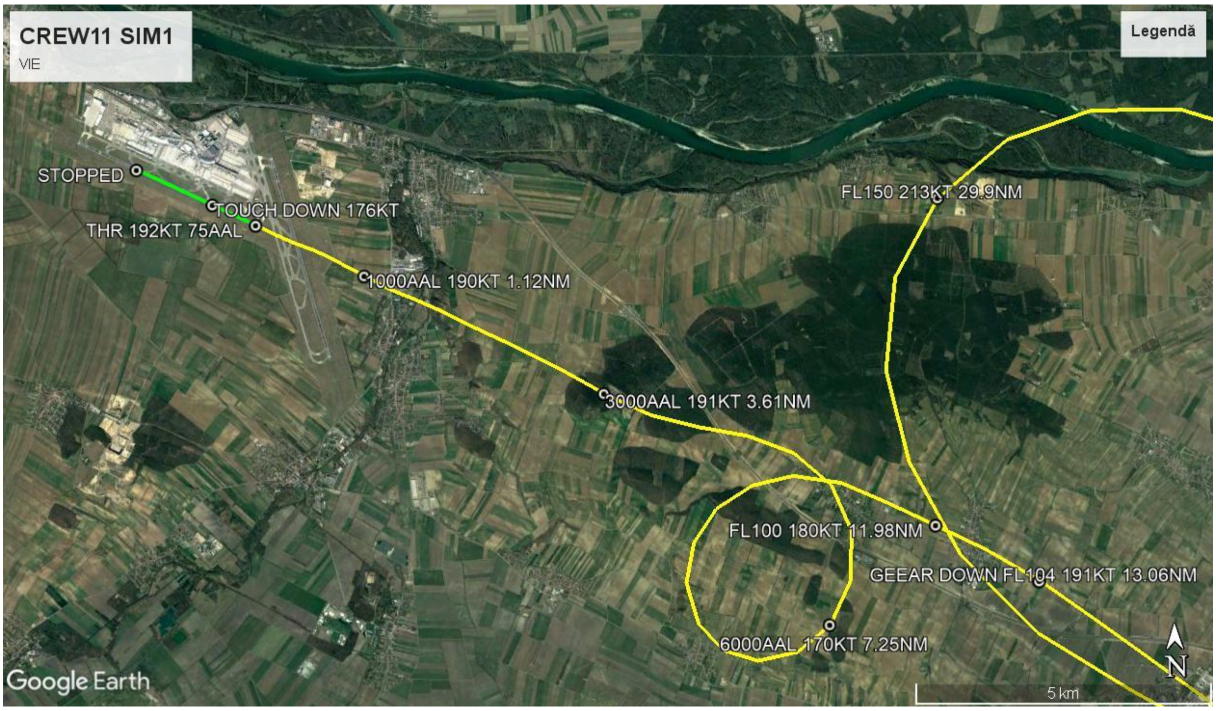


Figure 74. Crew 11 simulation 1 plan view (zoomed)

CREW 11 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		48.5	218	-0.5	12
FL100		11.98	180	-12.02	-26
3000 ft		3.61	190	-1.39	24
ALT AT THR	75		192	THR IAS	26
LANDING	SUCCESSFUL			THR ALT	25

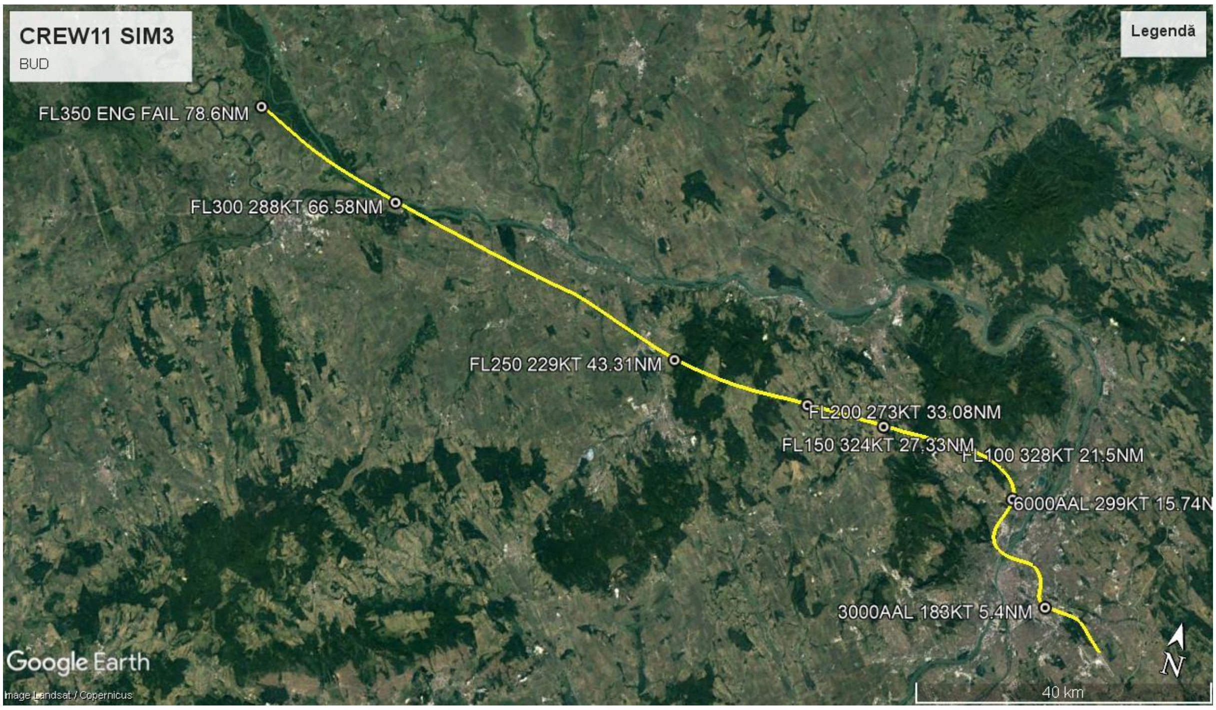


Figure 75. Crew 11 simulation 3 plan view

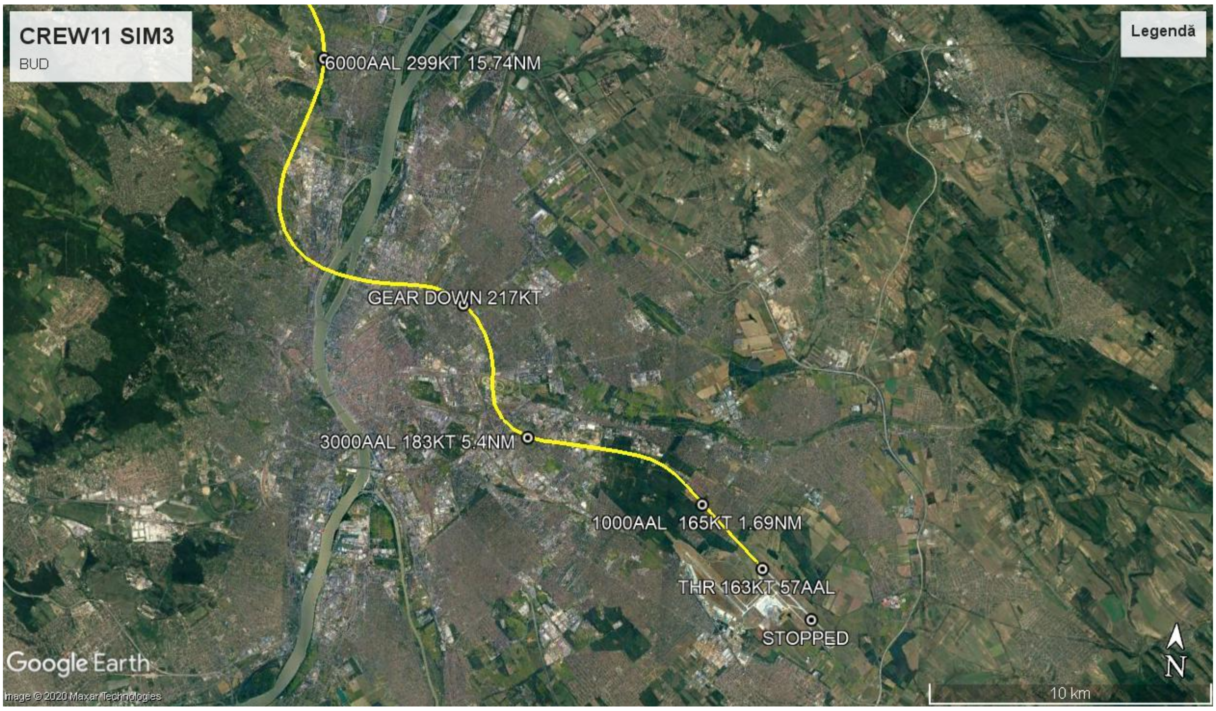


Figure 76. Crew 11 simulation 3 plan view (zoomed)

CREW 11 PROFILE SIM 3

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		33.08	273	-6.92	67
FL100		21.5	328	1.5	122
3000 ft		5.4	183	-0.6	-7
ALT AT THR	57		163	THR IAS	-3
LANDING	SUCCESSFUL			THR ALT	7

CREW 11

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	2.25	FL300	2	FL300	0.25
FL200	2	FL200	2	FL200	0
FL100	2	FL100	2.2	FL100	-0.2
6000 ft	2.2	6000 ft	2.4	6000 ft	-0.2

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	2.25	FL300	1.666666667	FL300	0.583333333
FL200	3.4	FL200	2.25	FL200	1.15
FL100	3.333333333	FL100	2.166666667	FL100	1.166666667
6000 ft	2.75	6000 ft	2.75	6000 ft	0

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	2.25	FL300	1.833333333	FL300	0.416666667
FL200	2.7	FL200	2.125	FL200	0.575
FL100	2.666666667	FL100	2.183333333	FL100	0.483333333
6000 ft	2.475	6000 ft	2.575	6000 ft	-0.1

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	
3	3	0	CREW WL Δ
			0
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
3	3	0	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	
3	2	1	CREW DM Δ
			1
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
3	2	1	

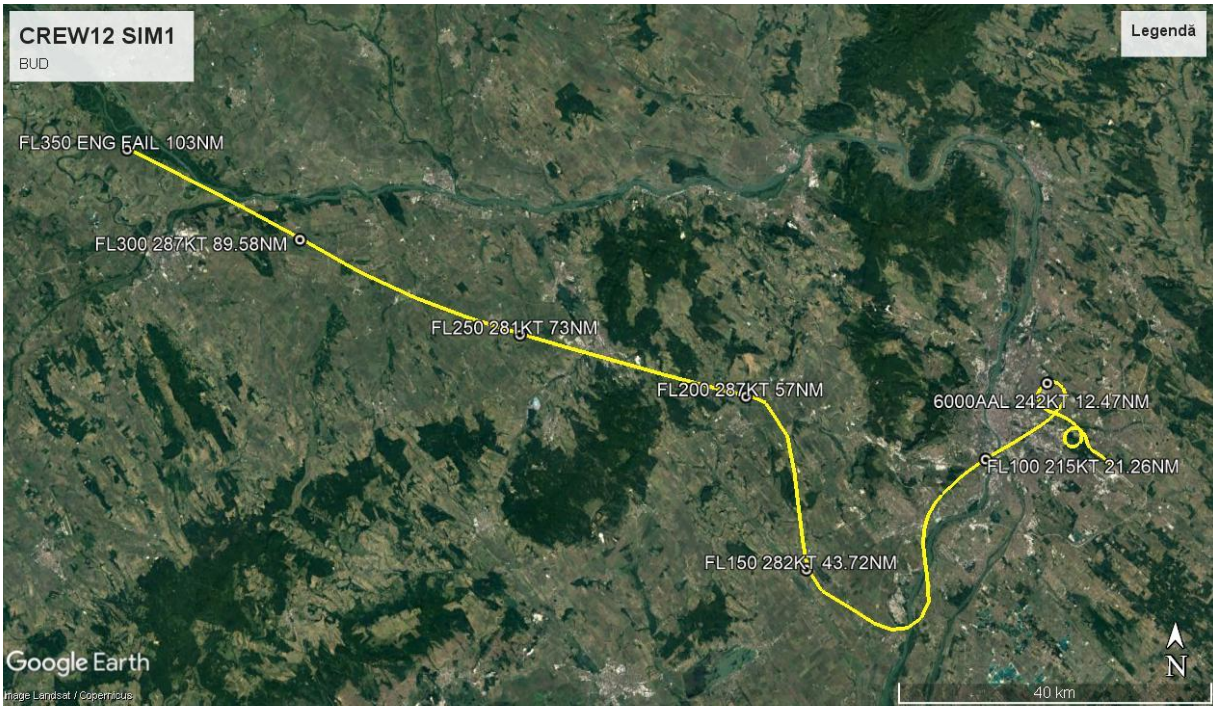


Figure 77. Crew 12 simulation 1 plan view

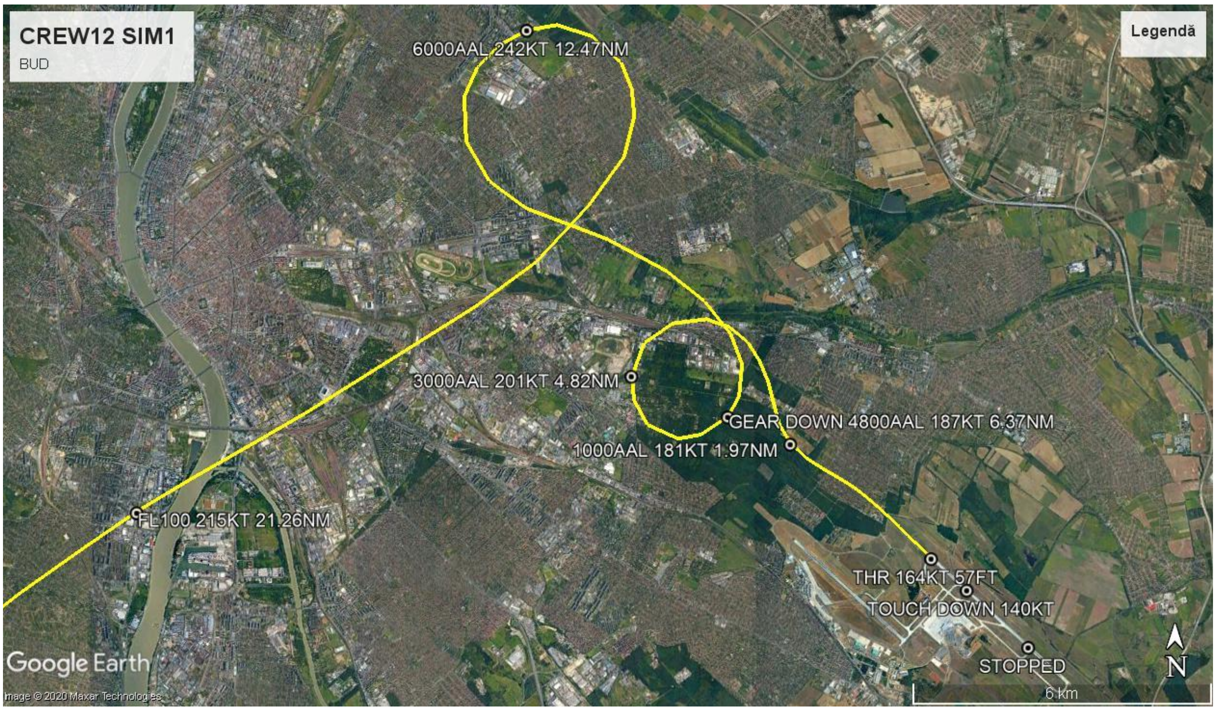


Figure 78. Crew 12 simulation 1 plan view (zoomed)

CREW 12 PROFILE SIM 1

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		57	287	8	81
FL100		21.26	215	-2.74	9
3000 ft		4.82	201	-0.18	35
ALT AT THR	57		164	THR IAS	-2
LANDING	SUCCESSFUL			THR ALT	7

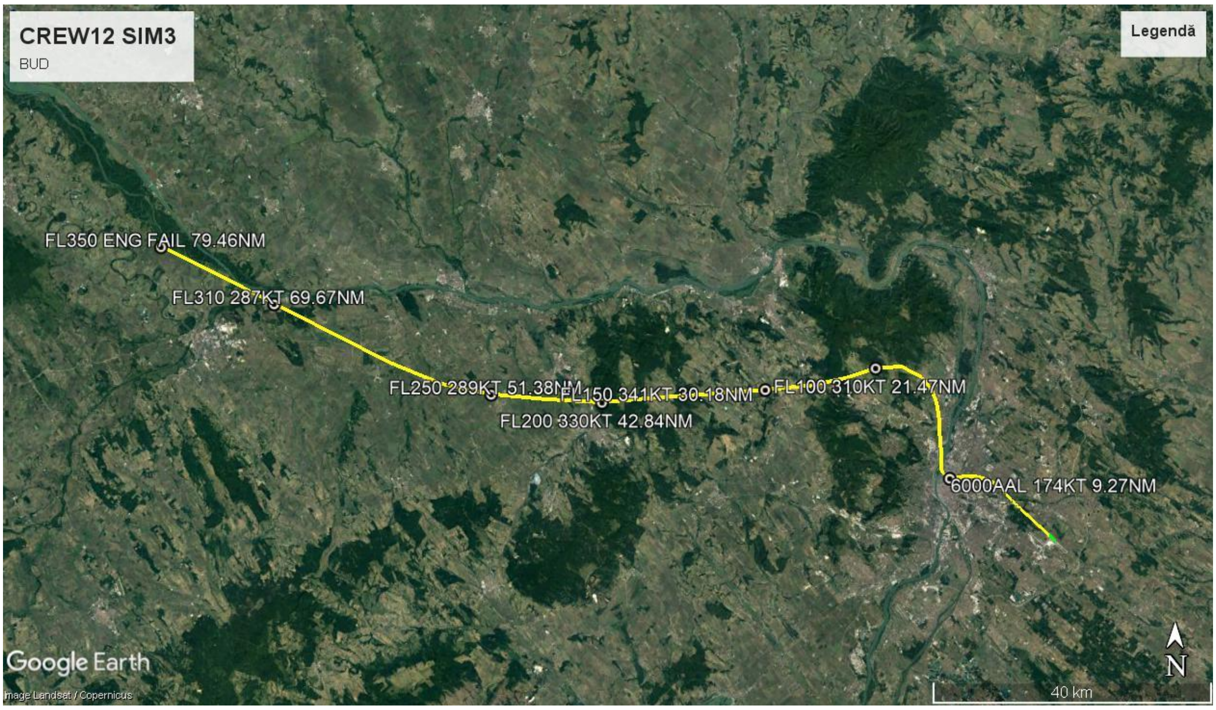


Figure 79. Crew 12 simulation 3 plan view

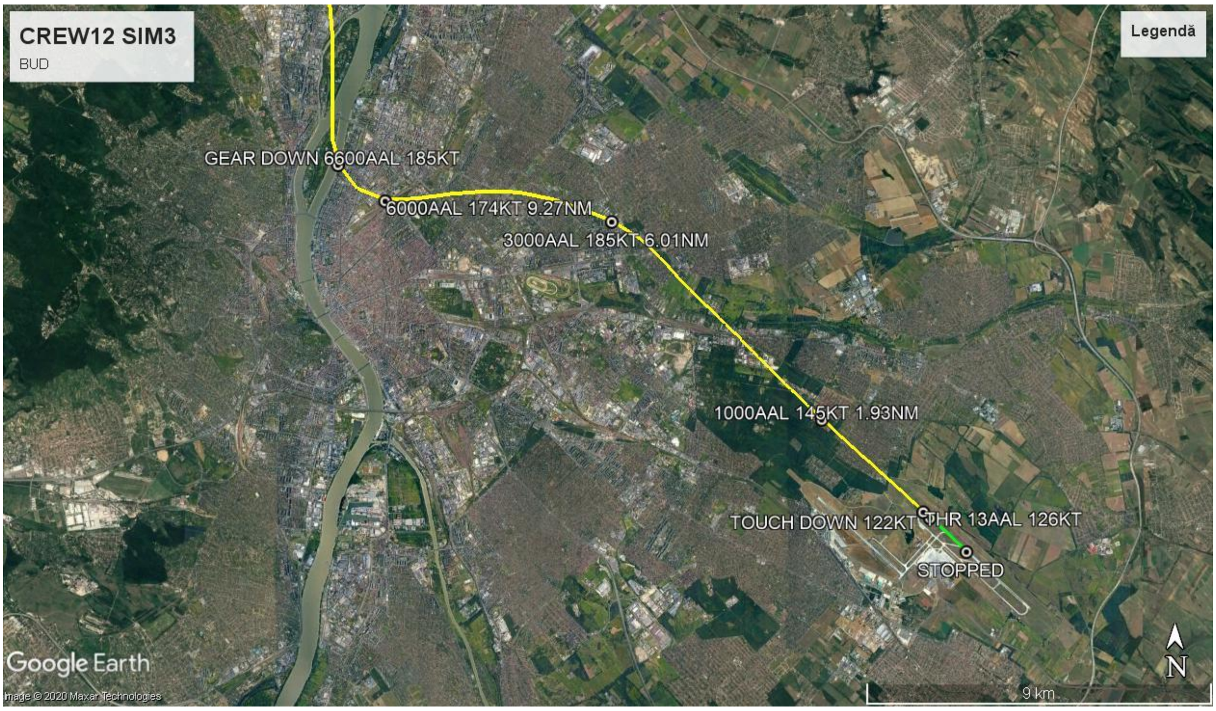


Figure 80. Crew 12 simulation 3 plan view (zoomed)

CREW 12 PROFILE SIM 3

FL/ALTITUDE		DIST. TO RWY	IAS	Δ DIST	Δ IAS
FL200		42.84	330	2.84	124
FL100		21.47	310	1.47	104
3000 ft		6.01	185	0.01	-5
ALT AT THR	13		126	THR IAS	-40
LANDING	SUCCESSFUL			THR ALT	-37

CREW 12

China Lake Situational Awareness Rating Scale

CM1 SIM 1 WGHTD. SA AVRG.		CM1 SIM 3 WGHTD. SA AVRG.		CM1 Δ SA	
FL300	3.333333333	FL300	2	FL300	1.333333333
FL200	3.333333333	FL200	2	FL200	1.333333333
FL100	3.666666667	FL100	3.333333333	FL100	0.333333333
6000 ft	4.5	6000 ft	2.75	6000 ft	1.75

CM2 SIM 1 WGHTD. SA AVRG.		CM2 SIM 3 WGHTD. SA AVRG.		CM2 Δ SA	
FL300	3.5	FL300	1.8	FL300	1.7
FL200	3.75	FL200	3	FL200	0.75
FL100	3.75	FL100	3.5	FL100	0.25
6000 ft	3.5	6000 ft	2	6000 ft	1.5

CREW SIM 1 WGHTD. SA AVRG.		CREW SIM 3 WGHTD. SA AVRG.		CREW Δ SA	
FL300	3.416666667	FL300	1.9	FL300	1.516666667
FL200	3.541666667	FL200	2.5	FL200	1.041666667
FL100	3.708333333	FL100	3.416666667	FL100	0.291666667
6000 ft	4	6000 ft	2.375	6000 ft	1.625

Bedford Workload Scale

CM1 SIM1 WL	CM1 SIM3 WL	CM1 WL Δ	
7	4	3	CREW WL Δ
			4
CM2 SIM1 WL	CM2 SIM3 WL	CM2 WL Δ	
8	3	5	

Modified Cooper-Harper Rating Scale

CM1 SIM1 DM	CM1 SIM3 DM	DM Δ	
8	3	5	CREW DM Δ
			5
CM2 SIM1 DM	CM2 SIM3 DM	DM Δ	
8	3	5	

Appendix 6 – Initial interview protocol and transcriptions

Protocol

In the case of crew number 1, the interview took place via Skype. For crews 2 and 3, the interview was conducted face-to-face in Budapest. All three interviews were audio-recorded using a mobile phone.

From crew number 4 onwards, all the interviews took place using www.myinterview.com, an online interview platform. The pilots accessed this platform following a designated link that I sent them. The questions were presented in written form, and their answers were video recorded then transcribed.

The three questions were:

- During your formal and informal airline training, have you ever been taught simplified calculations (rules-of-thumb) that were not written anywhere in the company or manufacturer manuals, knowledge passed to you verbally? Can you please give examples?
- If yes, how did the use of such simplified rules contribute to your flight management in normal and/or abnormal situations? Please give one or more examples.
- Looking at the QRH ABNORMAL AND EMERGENCY PROCEDURES TABLE OF CONTENTS (Airbus, 2019d, ABN), which situations would you describe as being *most critical* in terms of time available, loss of automation, descent profile, any other?

Figure 79 presents the QRH ABNORMAL AND EMERGENCY PROCEDURES TABLE OF CONTENTS (Airbus, 2019d, ABN), sent to the participants as a PDF file and available in the briefing room in print.

Continued from the previous page

Continued from the previous page

Figure 81. QRH ABNORMAL AND EMERGENCY PROCEDURES TABLE OF CONTENTS (Airbus, 2019d, ABN)

Transcriptions

CPT/TRI

1. Yes, I'd been given advices on how to make descent profiles, how to calculate, how to estimate the climb. Just short estimates about the energy state. Those were the simplified calculations, mostly.

2. I use computations everyday, every descent, in every, let's say, deceleration profile. In abnormal situations, I had no chance to use any simplified computation. Only in everyday normal operation.

3. Looking at the list of the possible problems I would say all engine failure definitely - that's something which I would put on the list. Ditching, emergency descent, forced landing, unreliable airspeed for sure, and anything associated with a fire - so all engine fail and any smoke, fumes, avionics smoke I would add to the list. And possibly, if I am away from any airports like, let's say, over the sea - bomb on board. Those are my choices from the list.

SFO (simulation incomplete due to COVID restrictions in Budapest, not counted in the research)

1. Yes, I have come across many of these rules of thumb during my studies and my airline career as well. They can simplify your job and increase your situational awareness greatly. For example, the 1 in 60 rule is one of these very fundamental ones and you can use rules for calculating descent profiles. Also for final approach rate of descent - if you take your ground speed and you multiply it by 5 you get roughly the vertical speed you need. And for the descent profile distance times 3 plus about 1000 feet gives you roughly the altitude. So yeah, definitely many rules of thumb came around during my career so far.

2. Well the descent range calculation for example I use very often. It's very good to make a rough estimate of where you need to start, where your descent point is. And yeah, along the way many others also come into picture.

3. Looking at the abnormal content list of the QRH describe as being most critical in terms of time available - well as you can see the highlighted elements here are quite critical checklists. We have here the all engine failure procedure for example, or the elec emergency config, summary for loss of automation is a good example. We have ditching, emergency descent, etc.. So what I see is that the most critical procedures are in bold and this leads the eye towards them so that when you have no time or little time available and the failure is more complex than the human brain will be able to pick it up easier.

CPT (simulation incomplete due to COVID restrictions in Budapest, not counted in the research)

1. Yes, there have been several, let's say informal, rules of thumb being taught to me. If I were to give you some examples - calculations for top of descent or ground speed calculation, sorry, the vertical speed calculation on approach from the ground speed, or the other way around. Or distance from the VOR beacon in case of an arc and so on so yes, I've been taught several. Maybe I cannot recall all of them but yes, I did.

2. Yeah, well, as I've mentioned before, I'm using very often a rule of thumb for the calculation of the descent profile. I'm using it routinely every time when we are flying. Very often I crosscheck the FMGC calculated profile. Sometimes it's a bit faulty or sometimes it's a bit "pessimistic" so I very often override it by myself and it works like a charm. Another idea or another example I can tell you - every approach I'm cross checking my vertical speed compared to the ground speed just to make sure that I haven't caught a side lobe of the glideslope. And just to give an example for an abnormal as well - once we had to divert due to some thunderstorms and they were not forecasted, they were not expected but it was a very hot summer afternoon and so then all the destination and alternate airports were fully thunderstorms so we had to divert to a location which was further away. We weren't anticipating it before so we had to make a very quick decision. We didn't have time for a proper planning so just the rule of thumb with the calculation of 2.4 T/hour as gross fuel flow on the 320, by the bearing and distance of the alternate selected we could come to a conclusion in about 5 seconds that we are able to divert there and that we will have the minimum fuel required on landing. And then we confirmed the calculation while we turned already to that airport. We ended up there with 1280 kg so our calculation was on the brink but it was saving the day because if we would have spent more time on calculations than we would have landed in potential emergency situation with low fuel. So that day was saved by the rules of thumb!

3. Which situations I would describe as the most critical from this list? From the first glimpse I would immediately look for the bold letters. Obviously they are kept in bold so the pilots will find it faster. This means that those situations, by the manufacturer at least, are considered to be the most restricted in time available. So if I combine everything which will end up in a high workload and a time critical situation I would say, for me, the procedure which is in question right now is the emer landing with ALL ENGINE FAILURE or maybe EMERGENCY DESCENT in a way that the initial workload is quite high combined with the situation which contributes to an emergency landing usually is very unpleasant with a lot of physiological factors so that's why I'm saying that a real emer descent is quite demanding. Or let's see the others. Yeah, EMER ELEC CONFIG for sure - you're losing a lot of automation, a lot of display, a lot of information. So no automation, no information presented only on one crew member, everything is on the captain's side so that is quite demanding and you very high level of crew coordination for that. What else? Oh yeah - SMOKE, FUMES, AVIONICS SMOKE checklist. Quite complicated and there a lot of intersections or decisions to be taken, lot of dots where you need to decide whether you continue that part or not on the checklist. You have to be very vigilant of the situation that you are faced with to avoid unnecessary steps on the checklist and it's, if I recall correctly, 7 pages long so that is also very demanding; combined again with the surrounding that you are faced with in this case - let's say you are having dense smoke in the cockpit, you don't see your colleague. So that is another one which I would highlight. For me these are the most, let's say "scary ones", if it answers your question.

CPT

1. Good afternoon! My name is ***. I'm a captain for Wizz Air for approximately 2 years now. The rules of thumb that I've been taught during the line training and throughout my career are mostly for the descent profile with the table of 3, adding subtracting winds and airport elevation. And as well what I use is the gear with the ground speed and actual speed on the speed tape for when to lower the gear before being stabilized at 1000 feet.

2. In normal situations I use the ones for the descent profile and gear extension. For the abnormals, for the engine failure, dual engine failure I've been taught to use 2NM/1000

feet to get to the airport and that's what I'm using in simulator sessions or if, God forbid, this might happen in real life.

1. For the abnormal QRH checklist the most time critical obviously is fires and a lot of common sense is taken into consideration there. A checklist can be delegated as long as one person flies and gets to the airport as soon and as fast as possible. Also, the pressurization memory items, rapid descent, emergency descent, I think, are very valuable. In terms of complexity of the QRH checklist I think that the EMER ELEC is rather complicated and long to go through, as well as SMOKE/FIRE before you find and isolate the source. That could be a bit time consuming but otherwise I think they are quite OK.

CPT/LTC

1. Hi! Yes. In my past career I've been taught some of these. Not particularly in the airline because I think that most of the airline captains and the instructors try to stick to SOP instead of using unofficial rules of thumb. But some of them, I've heard and that I use, is for being stabilized at 1000 feet with the A320 or A321 is a simple calculation method by multiplying your ground speed by 10 and adding the airfield elevation gives you the altitude at which you have to extend the landing gear to be stable at 1000 feet. This actually works, I've been doing it for the past 8 years in the Airbus. Other rules of thumb, for example, before we had the newest radars on our , to calculate where the top of the cloud layer is, by simply using the radar is this 1 to 60 rule of thumb. So, if you project your radar 1 degree below and you look forward to 60 NM, then that 1 degree path below is going to give you 1NM below you basically. So that's 6000 feet below you so it's an easy rule of thumb for calculation using the radar. I'm not sure if it was really understandable how I explained it to you. And there were some (i.e. rules of thumb) in the general aviation but, to be honest, I can't recall them right now because it's been a long time ago that I've been using those.

2. So, I can give examples for the first one that I have been taught which is the calculation method for being stabilized at 1000 feet for the exact point of the extension of the landing gear. Especially in high workload situations, when you feel that the workload is peaking during the approach, especially during line training - at a glance you can see if you're going to make it or not or if you have to take prompt action by throwing the gear or you still have some time. This has saved me from a couple of go arounds in my life because whenever I felt that the workload was high I just check the ground speed, multiply it by 10, which is a really easy calculation, added the elevation of the airfield and checked my altitude. Immediately I can see if it was ok or not and if I saw that I was on the edge I knew that I had to use the speed brakes obviously to slow the down or I could advise this to the trainee or the first officer. So, yeah, rules of thumb - if they are used correctly and if they are correct, of course, can greatly increase your situational awareness as well.

3. The most critical from the list, based on, first of all, time available, I would say the emergency landing, all engine failure at the back side of the QRH, that checklist because we usually use that checklist for all engine failure at low altitudes. I think that can be the most time critical. The second point - automation, most critical I think is the unreliable speed indication because automation is there but the data it might use can simply be wrong so it can really mislead you. It's not just simply losing the automation, it's the automation misbehaving and I think that's even worse than not working. The third aspect was descent management or descent profile - so the most critical, I guess, we can mention here the all engine failure. Our Airbus 320 or 321 becomes a huge glider which we are not particularly used to and, well, we don't necessarily practice it every half a year, every year in the sim but maybe in every 3 years once; and the other thing is, we don't even

know at first glance which speed to maintain - if we should maintain the optimum relight speed 280, but in that case our rate of descent and angle of descent would be higher. Or if we should aim for a better glider performance so to keep green dot speed, but obviously in that case we have a high chance of clogging the engines and if that happens we have no chance to relight it. So, yeah, the QRH can give you guidance on that but it's quite long. I don't think it can be expected from each and every pilot to know this procedure by heart so I think this is one of the most critical from descent planning aspect.

SFO

1. Dear colleagues, good afternoon. My name is *** and, as per this questionnaire, I would like to tell you couple of things about rules of thumb which was passed to me during my training as an airline pilot. For example, for the descent profile, when we calculate the descent, roughly it's 3 miles for each 1000 feet in normal operations with both engines running. Another calculation for the descent profile I'm doing regarding the wind - if I have headwind or tailwind, I'm subtracting or adding altitude regarding to the environmental conditions. Like 1000 feet for each 30 knots of tailwind or I'm adding at my current altitude 1000 feet for 30 knots of headwind. Another rule of thumb which I use quite often, for example, for configuring the, for when to put the gear down I have my own calculation according to the ground speed and airport elevation just to give me a rough idea when I should lower the landing gear in order to be stabilized regarding the company limitations for stabilization criteria.

2. Regarding the second question - I'm using on a daily basis these rules of thumb and it works 99% of the situations according to the descent profile which I was discussing in the earlier video.

3. QRH abnormal checklists - I would say that the EMER ELEC CONFIG for me personally is the most ambiguous or demanding, even though I understand fully what is written in the QRH abnormal. But regarding this third topic, for me, the EMER ELEC CONFIG checklist in the abnormal chapter of the QRH is the most time consuming or demanding.

CPT

1. Hello! The only rules of thumb advised that I have received during my airline training, that I remember at the moment, is when I started my career, in my first company. It was regarding the descent profile. So, in the school, I was taught that if I descend on a 3 degrees glide path I have to multiply the ground speed by 5 and that would give the vertical speed in feet/minute. But the rules of thumb that I was taught is that I have to multiply the descent angle by 2, to subtract 10% - initially it sounds complicated but it's not, trust me. So, you descend on a 3 degree descent angle, let's say you are at 50 miles at FL 150. 3 degrees multiplied by 2 is 6, minus 10% is 5.4. So actually you have to multiply your ground speed by 5.4 and that makes the rate of descent in feet/minute that you have to take for that particular ground speed. If I was high, I knew I had to increase the vertical speed. So if I was high, I had to increase the vertical speed. So, if I was at 50 miles at FL 200 normally I would have had to descend by 1500 feet/minute but I had to increase it because I was above. But I never knew exactly how much. So then they gave me this rule of thumb. So at 50 miles at FL 200 that makes it a 4 degree descent angle. Multiply by 2, that makes 8, minus 10%, minus 0.8, that makes it 7.2. So now we have the gradient of 7.2 and this multiplied by the ground speed gives us the actual rate of descent to descend on this particular 4 degrees descent angle.

2. This simplified rule, during the normal operation, is been quite a few times that it really used me. When, for example, the FMS was wrongly set up and, as you know, the FMS - garbage in, garbage out, GIGO, but these rules of thumb I always have a backup of the descent profile in my head. And not only when the FMS is wrongly set up. Sometimes I'm unsatisfied with the descent profile that FMS is doing. And when I am unsatisfied I just take it manually and that's it. And it always works perfectly, smooth to make an idle descent profile, at least to the final approach point - which I am more than happy to have it. In abnormal, well let's say, in abnormal operation it helps me a lot in the simulator. I'm not bothering at all with this descent profile and I'm just concentrating on the abnormal situation management. The rule of thumb is in the back of my head. I have some thresholds so I do another calculation at let's say 15000, 10000, 5000 and I adjust the vertical speed and that's it. So it helps me out by giving me a lot of spare capacity during the abnormal, but mainly in the simulator.

3. I would say that the abnormal checklist, from the academical point of view, yeah, it's the correct steps described over there. It gives you each correct step. In regards to time available, it should work fine. In case of loss of automation it should be fine. The descent profile - you're going to realize it eventually but I think it becomes a little bit critical when you combine them. Initially it is going to be the startle effect until you gain a little bit of awareness but actually is almost no time to regain awareness you have to start descent immediately and you have to descend on a specific profile - we will see how it looks in the sim. Thanks!

SFO

1. Hi Cristian! During my airline training I think I got rules of thumb only about descent to have a 3 degrees profile. Also there were a lot of theories and in the end you are just using what suits you best. For example, the height times 3 and also the headwind or tailwind times 3 to add or subtract to have a 3 degrees profile. I cannot recall any other rules of thumb, just looking now at the QRH I see hydraulics here so I think it's an easy one - if you see hydraulics and you have doubts whatever is failing for example just imagine an airfoil and in the hydraulics and if yellow, for example, is failing then you will have the flaps low or locked. Other than that I cannot any rules of thumb and as well in the manuals.

2. In general we are flying to airports that are pretty standard but there are some examples like Vienna where the controllers - they are very good and taking on the right profile. But the situation awareness and just to have just an idea where to expect some shortcuts because the STARs are huge and immediately they can subtract 40 miles of track miles. So is good to always calculate also in your head with the rule of thumb what to expect and how to fly it.

3. Looking at the QRH abnormal content list, the most scary would be all engine failure and as well the smoke in cockpit to have it which would draw a line between pilots and the situational awareness can really go down especially in a bad day. But, being a glider pilot, for all engine failure in a good day I think is super manageable in Europe. That depends on the length of the runway and the weather. But this would be the most time consuming and is drawing the line between pilot flying and pilot monitoring as the QRH content is quite extensive and would be nice to have some rule of thumbs.

SFO

1. Yes, in Oxford Aviation Academy we had a couple of rules of thumb. Quick one I can remember, for example, on a 3 degree glide, 5 times the ground speed should give us the rate of descent. Something like 1 m/s would be, more or less, 2 knots. So, in Russia for example, when they give the wind speed then you just take twice as much if you want it in knots. There is also the check error angle, the 1 in 60 rule, so track error angle would be the distance of track times 60 divided by the distance gone. This is what I can remember. I'm sure there are many more of these useful ones but this is what I can remember quickly.

2. Well, the m/s into knots I used when we were flying to Russia and they give the wind speed in m/s and it's so easy to just convert it because we are much more used to knots so when they say "the wind is 4 m/s from here and there then you just make it twice as much and then you are more familiar with what you are supposed to feel on final approach. I also used the 3 degree glide - 5 times the ground speed, it's a very easy calculation and Airbus is giving us this ground speed so, when I did raw data in the simulator it's easy to sort of know 700 to 800 feet/minute and it keeps you nicely on the glide.

3. So, most critical from that list.. The first one was time available so I think, following an emergency decompression, emergency descent, the first one should be the mask, I think that's very time critical because we might have only seconds before we pass out and be incapacitated. In terms of loss of automation - I think could be unreliable airspeed because it will fool us in every way as it happened before so I think it's very critical disengaging the automation because it will just try to kill you. Next one was, in terms of descent profile, I think all engine out - trying to glide down that's for sure that the descent profile will be critical to get right because you only have one chance to get right. And any other critical - I think maybe a bomb on board would be very critical which can go many different ways and that's why it's very difficult for the crew to organize themselves and stay on top of it.

SFO

1. Yes, there has been and this has mostly to do with management of the descent planning. So there are different captains who calculate their 3 degree descent profile when it comes to descending for approach and landing. There are some rules of thumb which are currently written in our manuals but when it comes to actually calculating these rules of thumb then we have captains who do 5 times the ground speed or the altitude divided by 3 - that will give the distance which you will need to lose. This last one you will have to take into consideration the wind - it is not calculated here. Those are the first two I can come up with right now.

2. Abnormal situations - I didn't really have so far. When it comes to normal operation, yes, it has been. My previous base used to be quite a small airport so when it came to the descent we were basically given descent from cruise all the way back down to the ground pretty soon so we had complete freedom when it came to descending according to a profile which we calculated. So, I use both techniques and eventually the one with 5 times ground speed was most convenient for me.

3. I think that is the all engine fail as this takes into consideration that, as soon as something would happen, that your first priority would be to restart one of the engines. So, with the time available and descent profile go a little bit connected to this to. As descent profile - in this checklist they have a certain speed and a certain descent profile. As time available,

at some point, it will become harder to focus on restarting the engines. So I think that the all engine fail checklist is the most critical in this part. Yeah, loss of automation, that is of course one of the consequences of having both engines failed. So, yeah, I think that would be the most critical in time available and descent planning taking into account with this as well.

SFO

1. In the previous operation on the Twin Otter we had a whole bunch of rules of thumb because a lot of it was not even in the manuals. That just came out of experiences but I have a really hard time finding examples of those. I know that for every different flaps setting and with every different power setting we got a different rate of descent so we could fix that up and then with the distance leave it all the way to the end and then you would make a perfect almost glide with power into the runway, into the approach. Now on the Airbus most of the rules of thumb we use is for the estimation of the top of descent, what kind of rates or vertical speed you need on final approach compared to your ground speed and maybe for the crosswind calculation to see how much of the wind component you actually use for the crosswind and how much crosswind that gives you. Yes, that's your first estimate but afterwards you go into the tablet or the box and it gives you your actually, or at least a better calculation of it. But for the initial calculation for top of descent, descent rate, especially in the sim during the training if you're doing anything raw data.

2. Like I said, in normal operation, you have all the time in the world. You may be estimating something by a rule of thumb calculation but afterwards you will check it with the box, or with the tablet, or whatever way to know that you're correct, or adjust accordingly. But you have all the time in the world so it's not really an issue. The rules of thumb come in handy when you are really time short and you need to do something immediately and at least you know you're roughly right from the beginning of dealing with the abnormal situation. And from there on, once you go through your ECAM, through your emergency checklist, you can keep checking your profile but you know at least the initial descent rate, the initial pitch, what's correct and doesn't make the situation worse so you can create some more space to deal with the emergency.

3. Looking at the QRH abnormal content list right now and it's alphabetical, amazing, makes it easy to find stuff, but the time critical or most essential that's of course not in this kind of order. The thing I experienced, with my limited experience, is that most of the emergency situations, abnormal situations, normal situations, you always have time. People rush into doing something but it's really important to not jump in it. The ones that I find time critical is also depending on the phase of flight you're in, of course. But definitely anything smoke or fire related, which is uncontrollable, is definitely very time critical. In EMERGENCY ELEC CONFIG you are time related if you cannot recover any of your electrical systems or of your electrical generating systems but, then again, you still have half an hour on your batteries. The engine failure, all engine failure that we are going to do today - if you are at cruising altitude, there is a lot of time, especially in the region where we are operating. There will always be an airport available to you within, let's roughly say, 60 to 80 miles range. Then it's more of the mountains and stuff that you have to take care off. Not necessarily time critical. Depressurization is time critical until you reach below 10,000. Still, perfectly flyable afterwards, all things taken into account. Bomb on board - very time critical but you don't know what kind of time you have so, yeah, make your decisions, if it's real and you find it, yeah, definitely. Volcanic ash will maybe give you again those engine failures depending on where it is. Even if you have the landing with the slats, flaps jammed or in an abnormal position you will find that out at lower altitude.

That makes it a little bit more critical, but, then again, if you can either retract them again or keep flying you still have a perfectly still flyable situation and then it comes down to your fuel how much you can troubleshoot. So, fuel, is again time in that matter and any kind of serious fuel leak will give you limited time to deal with this. Most of the failures that we get, even dual hydraulics, going into alternate law, it is still an and if it's still controllable, it is still flyable. Then the time critical is not really there, it's your situation awareness and prioritizing so you can make a safe landing and go back to any airport and make sure that the and the passengers and the crew make it safely out of this situation. Icing can be quite critical if it's severe but, then again, we have some shedding procedures for that and, if you can get out of the icing, you will lose it again, that's what the is equipped for. Although, we do get rushed into dealing with these emergencies, there is, most of the time, quite a lot of time to do it and there is not a lot of situations in which your becomes completely uncontrollable. Yes, what we had a few years back with the unreliable speed, that is dangerous. Because that is something that I never practiced in the sim. I don't even know exactly what it looks like. Yeah, we did it once or twice but it's something that will definitely startle you and that becomes the danger then. But if you still disconnect everything and fly your pitch/power settings you should be able to get out of that as long as you have the wits to deal with that.

CPT/LTC

1. Yes, I did get some rules of thumb. The most used one is for descent path using just mental computation. An example that I've got, but not during the formal training, is the latest altitude to extend gear, for instance, based on the ground speed. This include everything, the airspeed, the tailwind or the headwind and that leads to being stabilized at 1000 feet according to our company. I do use this one.

2. One rule that I use is the computation of the latest altitude based on the ground speed and airport elevation - ground speed plus airport elevation gives the latest altitude at which we should extend the gear. How does it help me? It's simply, I've never been unstabilized during my entire career life on Airbus. So I think it's a good one and ground speed includes wind, airspeed, airport elevation and based of that I extend latest the gear. It helps me, I don't have to think too much regarding the stabilization and I know that if I passed that point that I would be not stabilized.

3. I've never had a real abnormal situation, I just had trainings, like everybody. And based on the abnormal situation during training I can say that for me would be the time available and that's because the QRH is very, let's say, not well structured and, in order to deal with the situation, you have to read a lot of information that you actually don't need for that specific situation.

CPT

1. s actually part of the informal airline training. Some guys that were flying for a long time the Airbus were telling me a rule, for instance, what's the best optimum cruise level, which is 560 minus 3 times the weight. So this is a rule of thumb. The other were developed by myself or heard from other guys.

2. Well, I was mentioning previously that rule of thumb of the optimum cruise level. This is very useful because sometimes, FMS is still performing a calculation if you change some inputs inside and you don't have displayed on the MCDU what is the optimum cruise level but if ATC is asking you, you can instantly reply "I can accept this level.." or "I request this level.." so it's useful.

3. As in any QRH abnormal checklist the risk is that you don't have the big picture. First of all, there is this startle effect, you are surprised. Then you are jumping to the checklist but actually, to properly implement the checklist you have to know what's gonna follow in order to have the big picture. Otherwise, if you are applying step by step you can be just lost in applying procedures even without understanding them. So to answer this question actually, the descent profile is a threat, it's most critical because it's something that we are not used to and, for sure, it's totally against our nature.

CPT/LTC

1. Yes, we worked out some rules of thumb. One of them could be the approach, the descent vectoring approach: multiply your ground speed times 5. Another one could be, for example, on a dual engine failure, using twice the 3 degree glide slope - for example, using 6 degrees which would leave you at 3000 feet at 5 NM from the runway. Also, when flying in hot weather I remember we had some for descent rates during approaches into Doha. I don't remember exactly what the calculation was but they used to teach us those numbers as well.

2. Yes, of course, they do help you on a normal day situation. On an approach, for example, if you're doing 150 ground speed you know your descent rate should be somewhere around 700 so it does work. Another one would be for the descent into an airport using 3 times your altitude - should be the distance to the airport plus you usually add about 10% to that for deceleration so the rules of thumb we do use on a daily basis and they do help you with normal operation.

3. For time available I would say probably the worst one would be a fuel leak. That's the one that usually you have the least amount of time available in a single scenario. Loss of automation - probably an unreliable airspeed, that causes the most chaos in the cockpit and managing the flight and flying the is the main concern there without any kind of automation or information. If you put them all together, the most critical situation that takes time available, loss of automation, I would probably say an all engine failure, but at a low altitude. So low altitude dual engine failure would probably take everything into consideration - it would be the worst situation and the most critical.

SFO

1. I've been taught some rules of thumb. I think it depends on the instructor: some of the instructors were teaching us some tricks. To be honest it doesn't happen too often. It's a matter of getting a bit outside of the box and the time in the simulator is quite limited so there are not so many instructors teaching us too many tricks but some of them - they are trained to do it. Just few examples: math calculations in order to find out our rate of turn, or our how much height we lose during dual engine failure or the 1 in 60 rules, stuff like this. Generally, I saw that in our manuals there are a lot of formulas and math calculations to help us during flight and especially during the emergencies.

2. In the normal procedures during our flights we are using everyday the rules of thumb to calculate the top of descent. Sometimes we need to calculate the green dot speed - especially when we are heavy and we need to turn, to perform a sharp turn immediately after departure and we need to keep the green dot speed + 10 and just before the departure, if we want to crosscheck the green dot speed with the one which is calculated by the computer we just use it, we use the calculation. Of course the aeroplane helps us a lot and it calculates the top of descent, by example but the calculation sometimes is not very accurate so we are double checking the calculation and we are starting our descent when we think that it's better sometimes, or if we are under radar vectors and the predictions are not very accurate so we need to calculate it. In the abnormal situations during the trainings we calculate, by example, how much altitude we lose during a dual engine failure. I don't remember exactly all the situations but for sure there are some rules of thumbs that we are using in the manuals. We can find for some procedures some indications on how to calculate faster or how to find ways to help us with some shortcuts, some tricks in the abnormal procedure.

3. Thinking about the most critical situations and talking about the time available I would say that one of the most critical situations which requires very quick reaction is the rapid decompression or explosive decompression or maybe fire and smoke - we need to react fast and we need to take decisions very fast, especially for the rapid decompression when we are at cruising altitude and we are FL390, 380 and we lose the pressurization we have maybe few seconds to take the oxygen masks in order to be able to conduct the flight and to descend safely. Fire and smoke as well - we don't want to end up intoxicated with the smoke or to stay too much in the air when we have a fire so we need to descend and to take action fast. When thinking about loss of automation - maybe the unreliable airspeed is one of the most critical situations. You have to fly manually, you don't know your speed and you just have to fly the aeroplane like a Cessna, with pitch and power. So during this time you have to maybe to hold or to climb above the safety altitude in order to stay safe and everything should be done manually with not so many informations displayed on the PFD. The descent profile - one of the most critical situations which involves the descent profile is, of course, dual engine failure. You don't have trust and all you need is to keep the aeroplane under control while descending towards an airfield or maybe an unprepared field for the landing, or maybe ditching. I think these are the most critical situations - unreliable airspeed and fire. They are very demanding and require skills, all your knowledge in order to bring the aeroplane down safely.

SFO

1. I remember during my training that I learned from the instructors how to calculate my descent profile, using a normal descent of 3 degrees, using ground speed or distance versus altitude, even how to use a steep descent up to 6 degrees glide path.

2. I'm using everytime when I am flying to calculate my descent profile, for optimization. When I know that air traffic controllers will provide me radar vectors for shortcut instead of letting me to fly the full approach when the managed descent will not work properly.

3. In my opinion the most critical failures are fire and smoke that cannot be removed by the crew. With those two, time is against me. I need to be on the ground now, in the next moments, to have a chance for survival. With dual engine failure it depends on the flight phase. If I am very close to the ground like Sully, times is against me again and the most I can do is to do the memory items. Definitely I won't have the time to use the QRH. If I am on the cruising level, yes I have time. I'm limited on time but I have time to try to relight the engines, to prepare the cabin for landing, the for landing and to calculate how far I can go for landing.

SFO

1. Yes, during my formal airline training, the initial training I was taught some matters for calculation of descent path profile. For example - how to convert my airspeed into my required vertical speed for a 3 degree path and how to apply this maybe to different degrees of glide angle. Also, already during my airline career I picked up some techniques how to make decisions on when to start to deccelarate, or to lower the gear, or to help myself to intercept the glide with continuous descent.

2. I would say definitely yes, especially for normal day to day operations where every flight you have to make quick decisions on your descent, when to start the descent, where you are in accordance with your descent path profile. Also, you make your whole life easier if you use rules of thumb multiplying everything by 3, instead of everytime calculating. Also, every day is slightly different with regards to environmental conditions and then also converting variables like the wind into simple rules like, for example, for every 10 knots of tailwind you add 3 miles on your distance that you need. So, I would say definitely. For the abnormals, I have to say I don't have so much experience. I was not really taught how to apply this. I would still apply normal ones into the abnormal situation as a very quick guidance because the first part of the abnormal situation is still to fly the .

3. As far as it goes for the most critical in terms of time available I would definitely say that it depends a bit on the proximity to the ground. So, let's say a dual engine failure or even a single engine failure at a high altitude is slightly less time critical then a low altitude engine or dual engine failure. But, in any case, I would rank these quite high. As well as definitely the fuel leak and, depending on the aggressiveness of the fuel leak, if it's a slow leak or a fast one, it definitely reduces your available time in the air. As far as loss of automation I would say a dual engine failure also puts you in a sort of emergency electrical configuration which significantly reduces the availability of automation so I would rank dual engine and also the emergency elec config, as well as anything which deprives you of your navigation so let's say unreliable airspeed can be as well in this position. Also, for time critical I definitely forgot to mention the smoke and fumes which are not only dangerous for the time in the air but also can present more time critical because of the health concern. As far as descent profile goes, I would say that it's less of a critical thing. It can be in case of, let's say, unreliable speed where you have to pull out all these checklists, determine the speed. It's more difficult to go for the configuration of the towards the final approach and also at the end it puts you in the direct law.

CPT

1. Yes, there are some rules that we actually just know by our instructor and they are not written anywhere and let's say those are rules of thumb.

2. The rules of thumb are used. I use them in normal situations and in abnormal situations. In the normal situation whenever it is a problem of time management. Abnormal situations I didn't have so many this far that I need to use them. So it was just lucky time, let's say but I have them ready to be used in case I need.

3. From the QRH list the most important abnormal situation that we can have are the dual engine failure and then another one that from my point of view is really important to know and I use it as memory item is the engine fire, tailpipe fire during start. So, that's it.